UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HIGH HEAD MODEL TESTS FOR THE FLATIRON AND POLE HILL FRANCIS-TYPE TURBINES AND TWO TURBINE BYPASS ENERGY ABSORBERS

Hydraulic Laboratory Report No. Hyd-348

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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SYMBOLS AND DEFINITIONS

Specific Speed, N_s, the speed in revolutions per minute at which the mathematically reduced turbine runner would operate to develop one horsepower under one foot of head.

Phi, ϕ, the ratio of the peripheral velocity of the turbine runner at the throat to the theoretical flow velocity, $\phi = \frac{\pi D_t N}{60\sqrt{2gH_e}}$

Sigma, σ, the ratio of the net pressure above the vapor pressure at the runner throat to the effective head on the turbine

$$\sigma = \frac{H_a - H_m - H_s}{H_e}$$

Water horsepower $= \frac{Qw\ H_e}{550}$

Turbine Horsepower output $= \frac{2\pi LNW}{33,000}$

Turbine efficiency $= \frac{\text{Water Horsepower}}{\text{Turbine HP Output}}$

Unit Horsepower $= \frac{\text{Horsepower Output}}{H_e^{3/2}\ D_t^2}$

Unit Discharge $= \frac{Q}{D_t^2\ \sqrt{H_e}}$

π = 3.1416···

D_t = Diameter of runner throat, feet

N = Rotative speed of runner, revolutions per minute

H_e = Effective head on the turbine, feet of water

H_a = Atmospheric pressure - feet of water absolute

H_m = Vapor pressure of water, feet of water

H_s = Head at outlet of turbine runner, feet of water

w = Specific weight of water, lbs per cu. ft.

L = Length of dynamometer arm, feet

W = Dynamometer load, pounds, measured on platform scale

Q = Rate of flow, cfs.

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Laboratory Report No. Hyd-348
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Subject: High head model test for the Flatiron and Pole Hill Francis-type turbines and two turbine bypass energy absorbers--Colorado-Big Thompson Project, Colorado.

PURPOSE

The purposes of the studies were to investigate the suitability of the reaction-type turbine to the unusually high heads at which the full size units will operate, to determine, as a basis for acceptance, the performance characteristics of the proposed turbine, and to investigate two energy absorber designs.

CONCLUSIONS

1. The model tests show that the Francis-type reaction turbine proposed by the Pelton Water Wheel Company and using the SF-4A runner satisfactorily fulfills the requirements set forth in Specifications No. 2996. The SF-4A runner was a modification of the SF-4 runner where the outlet ends of the blades were cut back 3/16 inch (model) to increase the outlet flow area (Figure 7).

2. The peak efficiency at the design Phi of 0.480 was 89.60 percent at wicket gate opening D (corresponding to 10 degrees) (Figure 18C). A best efficiency of 90.00 percent was obtained at Phi of 0.495.

3. The SF-4 runner did not provide the margin of power output desired by the manufacturer (Figures 7 and 18). The runner was modified by cutting back the outlet ends of the runner blades 3/16 inch to open the flow passages and increase the power output (Figure 7). This modified runner, designated SF-4A, produced the power margin desired.

4. The outlet piping from the model presented too much resistance to allow the turbine outlet pressure to be lowered enough to produce a "break" in the sigma-vs-efficiency curve (Figure 19C). However, values of sigma considerably below the design value of 0.030 were obtained and the efficiency remained satisfactory.

5. The admission of air into the inlet of the turbine draft tube had no noticeable effect upon the turbine performance.

6. The Pelton energy absorber (pressure regulator) vibrated and made a great deal of noise when it was operated (Figures 20, 21, and 22). The admission of air, as is required by the manufacturer, quiets the conditions appreciably, but at the larger valve openings the air inlet system seemed to be inadequate (Figure 23).

7. No definite evidence of cavitation damage was found in the Pelton absorber (Figure 22).

8. The velocity distribution at the outlet of the absorber draft tube was poor (Figure 23C).

9. The three-stage energy absorber vibrated very severely and made much more noise than the Pelton absorber (Figures 24 and 25). Air was admitted just below the relief valve (Stage 1) in the tests with small valve openings; but due to the presence of higher pressures in this region at large valve openings, the air inlet was sealed off. Air admission below Stage 3 under all operating conditions quieted the vibration and noise to some extent.

10. Definite evidence of cavitation damage was found in the region of Stage 2 (Figure 25).

11. Changes in the area of the second stage control produced changes in the pressure distribution and in the discharge. (Figure 26A, B, and D).

12. The velocity distribution at the outlet of the absorber draft tube was fair when no air was admitted at Stage 3 but became extremely poor with a high-velocity central jet when air was admitted (Figure 26C).

13. A minor change in the seat ring of the relief valve to remove an abrupt change in surface profile did not affect the operation of the absorber (Figure 28).

REFERENCES

1. Pelton Water Wheel Company reports submitted with a letter of transmittal dated November 30, 1951:

(a) Flatiron Model Turbine Tests

(b) Flatiron Model Pressure Regulator and Pelton Type Energy Absorber

2. Field trip report dated February 18, 1952 and entitled "Model studies for hydraulic turbine and energy absorber--Flatiron Powerplant--Colorado-Big Thompson Project."

3. Specifications No. 2996 entitled "Hydraulic Turbines For Pole Hill Power Plant and Flatiron Power Plant--Colorado-Big Thompson Project."

ACKNOWLEDGMENT

Respective phases of the test program were coordinated between the Hydraulic Machinery Branch, the Hydraulic Laboratory Branch, Region 7, and the Pelton Water Wheel Company.

INTRODUCTION

Pole Hill and Flatiron Powerplants are parts of the Colorado-Big Thompson Project and are located on the eastern side of the Continental Divide about 16 and 11 miles southwest of Loveland, Colorado (Figure 1). The rated head is about 825 feet at the Pole Hill plant and about 1,045 feet at the Flatiron plant. A single turbine with a 35,000 kva generator is installed in the Pole Hill plant. Two generally similar units are installed in the Flatiron plant, and these units have a combined peaking capacity of 63,000 kilowatts, the additional flow of water for the peak load being supplied by Rattlesnake Reservoir which forms the forebay to the Flatiron plant.

The 1,045-foot rated head at the Flatiron plant is somewhat above the 900- to 1,000-foot head limit usually accepted for Francis-type reaction turbines. However, it was believed that the best overall economy and performance could be obtained in this installation by the use of the Francis-type instead of an impulse wheel turbine. Specifications were issued stating the operating conditions to prevail and the performance to be required of a Francis-type turbine (Specifications No. 2996). The specifications also stated that high head model tests would be required and that a test report was to be supplied to the Bureau of Reclamation, and that acceptance of the design would be based upon the results shown in the model tests. The specific speed of the model was to be numerically equal to that of the prototype, and the model head was to be as nearly equal to that of the prototype as feasible, but not less than about 500 feet. The test facilitites and water at Estes Powerplant, where a 550-foot shut off head was available, were made available to the contractor without cost (Figures 2 and 3). The Pelton Water Wheel Company was awarded the contract on the basis of its bid and design proposals, and the company built a 4.21 scale model turbine. Low head tests were conducted in the manufacturer's plant and then high head tests were conducted at Estes Powerplant.

In addition to the turbine tests, tests were made on a 4.5 scale model of the contractor's proposed turbine pressure-regulating valve and energy absorber and on a 3-stage energy absorber proposed by the Bureau of Reclamation. The latter was called the "3-stage energy absorber" because energy dissipation was achieved by throttling, followed by sudden expansion at three points within the absorber. The models, together with the heavy test equipment and related piping, (Figure 4) were the property of the contractor and were shipped by him to Estes Park and assembled for the tests. At the completion of the program they were disassembled and returned to San Francisco. Precision test gages, counters, manometers, etc., were supplied by the Government. The tests were made under the direction of the contractor through its representative, Mr. Alex Sementovsky. The remainder of the 4 to 5 man test crew was supplied by the Bureau of Reclamation. A temporary timber and canvas enclosure was provided by the Government to shelter the models and test equipment that were located on the open draft tube deck of the powerplant (Figure 5).

Very brief reports of the model turbine and the Pelton energy absorber test results were prepared and submitted by the contractor. Also, a brief field trip report was prepared by the participating Bureau personnel (February 18, 1952). Many of the details of the test procedures, the test results, and the difficulties encountered in the high head test were omitted from these reports. In order to more fully discuss the test program and test results, and to provide a better knowledge of the problems and requirements of high head testing, this more extensive report has been prepared.

TURBINE TESTS

Permanent Facilities at Estes Powerplant

During the construction of Estes Powerplant an outlet was provided in the No. 1 penstock. An 18-inch pipeline and valve were attached. The pipeline entered the lower level of the powerhouse at elevation 7476.87 (Figures 2 and 3). The valve was motor-driven and could be operated from within the valve pit or at any location to which control lines were extended. The power lines to the valve motor were energized through a master switch in the powerplant control room. Provisions were also made for opening or closing the valve manually. A 4-inch, manually operated bypass was provided around the control gate so that the line could be filled before the 18-inch valve was opened. A 17.25- by 8.95-inch Herschel-type venturi meter was attached to the outlet end of the 18-inch pipeline inside the powerplant. This meter had previously been calibrated by an eastern university, and this calibration had been verified and extended by the Hydraulic Laboratory in Denver.

Model Installation

Temporary 12-inch piping was installed from the venturi meter through an opening in the powerhouse wall and then upward to the draft tube deck where the models were located (Figures 4 and 5). An expanding section increased the pipeline size to 16 inches and vaned 90-degree elbows turned the flow into the 11-foot long by 16-3/32-inch diameter horizontal inlet pipe. The inlet pipe was followed by a 26-inch long, 16-3/32- by 12-inch conic reducer and then by a 12- by 12- by 10-inch wye. Flow entered the turbine scroll case straight through this wye and flow entered the bypass energy absorbers through the wye branch (Figure 4). A needle valve at the entrance to the model energy absorbers prevented flow from entering the absorbers during turbine operation.

The model turbine, the turbine shaft, and the water brake dynamometer (Figures 6 through 16) were supported on a welded structural steel frame. This frame was welded to three heavy I-beams which were held to the draft tube deck by tie bolts that passed through holes drilled in the deck. Angle-iron straps were placed under the deck beams and over the I-beams, the I-beams were then shimmed to grade and the bolts drawn tight.

For convenience in testing, the turbine shaft was placed horizontal. This shaft was carried on ball bearings whose outer races were carried in sleeves that were in turn supported in other ball bearings (Figure 6). The sleeves carrying the outer races of the shaft bearings were prevented from rotating more than a few degrees by an arm that extended through the bearing housing. By measuring the force required to prevent rotation in the sleeves, the power lost in the bearings was determined. The torque load exerted by the 7-foot long dynamometer arm was measured with a platform scale. This scale was fitted with an auxiliary indicating beam and an oil dashpot which reduced the beam movement caused by the pulsating load from the water brake.

The draft tube discharged horizontally into a 5-1/2-foot diameter cylindrical tank. A 16-inch line carried the discharge from this tank over the side of the powerplant deck and down into the tailrace. A chain-operated butterfly valve in the line near the level of the tailrace was used to regulate the back pressure in the cylindrical tank. Although not shown in Figure 4, a gate-controlled standpipe was provided on the draft tube tank, and a 6-inch gate-controlled air inlet was provided on the 16-inch outlet line near the powerplant deck (Figure 5). A spring-loaded pressure relief valve was located in this air inlet line between the 16-inch pipe and the 6-inch valve.

A magneto-type tachometer gave the approximate instantaneous shaft speed of the turbine and was used to make the speed settings. This tachometer began to function erratically during the latter part of the tests and it was replaced by a strobotachometer. Speed regulation was made by adjusting the load on the dynamometer. An accurate count of the revolutions turned by the shaft in a given period of time was made with an electronic counter and an electronic interval timer. The counter recorded the number of impulses generated in a pickup coil by four permanent magnets as they were carried past the coil in a disk fastened on the end of the turbine shaft. The magnets were mounted at 90-degree intervals around the disk, thereby giving an impulse every quarter of a revolution. The electronic interval timer was connected to the counter with a double pole single-throw switch so that the counter and timer were started and stopped simultaneously. The average time to obtain a test point was 20 seconds.

The rate of flow was measured with the calibrated venturi meter and the turbine inlet pressure was measured with a Crosby 300-psi fluid pressure scale. The pressure in the draft tube tank was measured with open-water manometers when positive and with a mercury-filled U-tube when negative. A mercury barometer was used to measure the barometric pressure.

Model Tests

Two turbine runners, designated SF-1 and SF-4, were tested at Estes Park. The SF-1 runner was used in low head tests conducted at the manufacturer's plant, and only a few tests were made with it at Estes Park for the purpose of correlating the high head data with the low head data. Good correlation was obtained and the runner was removed from the test rig and the SF-4 runner was installed.

The model was placed in operation by closing the wicket gates and opening the air vents in the scroll case and then opening the 4-inch bypass to fill the lines. After the lines were full, the 18-inch valve was opened and the wicket gates were slowly opened to the desired setting. The speed of the turbine was regulated by adjusting the quantity of water within the water brake, and the flow through the brake was adjusted to a sufficiently high rate to prevent overheating. Runs were made through an appropriate range of speeds, at wicket gate openings of B, C, D, E, F, G, H, and J. These gate openings correspond to 6, 8, 10, 11, 12, 13, 14 and 16 degrees. The designation "I" was omitted to avoid confusion.

The efficiency of the SF-4 runner at the various wicket gate openings for the appropriate range of Phi (see Symbols and Definitions) is shown in Figure 18A. A peak efficiency of 89.5 percent was obtained at Gate D for Phi = 0.504. The design Phi was 0.48, at which the best efficiency was 88.9 percent. The unit horsepower versus Phi for the various gate openings is shown in Figure 18B. In stepping the power output up to the actual plant operating conditions and turbine size it was determined that the turbine met and slightly exceeded the 48,000 horsepower requirement of the specifications. The turbine manufacturer decided that there was too little margin and changed the runner to enable it to develop more power. The modification consisted of increasing the outlet passage areas by cutting back the ends of the runner blades 3/16 inch (Figure 7). The modified runner was designated the SF-4A runner.

The efficiency and the unit horsepower of the SF-4A runner for various wicket gate openings is shown plotted against Phi in Figure 18C and D. The efficiency increased to a peak of 90 percent for

Gate D at Phi = 0.495 and was 89.6 at the design Phi of 0.48. The unit horsepower was sufficiently high to insure an adequate margin over the required 48,000 horsepower output for the powerplant installation.

The curve showing the relation of efficiency to the unit horsepower, HP_1, at the design Phi of 0.48 is shown in Figure 19A, while the relation of efficiency to the full size turbine power output is shown in Figure 19B. The relation of efficiency to sigma, σ, is shown in Figure 19C. The lowest sigma obtained in the model tests was 0.0135. No lower values could be obtained with the outlet piping provided because the pressure in the outlet line could not be lowered further, and thus the point where the efficiency began to drop with decreases in sigma (the sigma break point) was not reached. This was not considered a serious shortcoming because the design sigma for the plant is 0.030, and the model tests were of sufficient range to show that the sigma break occurred at sigma values below 0.0135 to 0.0238, depending upon the wicket gate opening (Figure 19C).

The relation of the unit discharge to the throat Phi for the various wicket gate openings is shown in Figure 19D. The total discharge as plotted against horsepower output is shown in Figure 19E.

Tests were made in which air was admitted into the turbine draft tube through the piping shown in Figure 17C. No noticeable effect was found on the turbine efficiency and the piping was removed. All the test data reported above were obtained without air admission into the draft tube and with the piping removed from the tube.

ENERGY ABSORBER TESTS

Two very different types of turbine bypass energy absorbers were tested. The first was the type the Pelton Water Wheel Company has used for many years and was proposing for use at the Flatiron plant (Figures 20, 21, and 22). In this absorber, the jet from the bypass or pressure-regulating valve strikes a baffle which deflects the stream radially outward into a bowl. The bowl then deflects the water back under the baffle into the center of the passage and into the discharge diffuser tube.

The second absorber was a experimental design proposed by the Hydraulic Machinery Branch of the Bureau of Reclamation (Figures 24 and 25). It was called the 3-stage energy absorber because energy dissipation occurred primarily at three stages within the unit. Water entered this absorber through the turbine bypass valve, the valve forming the control of the first stage in the absorber (Figure 24). The flow traveled vertically downward through the inner tube and was then deflected radially outward and upward by the absorber bottom. The annular orifice created by the end of the inner tube and the absorber bottom provided control for the second stage of energy dissipation. The area of this orifice was adjustable from 20 to 50 square inches by shims placed between the cover and outer tube. After being turned upward, the flow passed between the inner and outer tubes and then entered the horizontal discharge tube. A fixed area orifice near the entrance of the discharge tube provided the control for the third stage of energy dissipation. A horizontal diffusing discharge tube completed the absorber. Air inlet manifolds were provided at the absorber entrance just downstream from the inlet valve and immediately downstream from the third-stage orifice.

The absorbers were connected, one at a time, to the discharge end of the needle valve which represented the turbine pressure regulator, or relief valve. This valve was connected by a short 10-inch diameter pipeline to the side outlet of the wye branch at the turbine scroll case inlet (Figure 4). Water was prevented from passing through the turbine during the absorber tests by a blind flange placed over the turbine outlet.

The Pelton energy absorber requires the admission of air just below the inlet valve to minimize cavitation and cavitation damage. Provisions were made for supplying this air, and the rate of flow was measured by suitable flat-plate orifices mounted at the inlet of a small tank connected to the air inlet manifold (Figure 22A). Similarly, provisions were made to supply air just below the inlet valve in the 3-stage absorber and in a manifold just downstream from the third-stage orifice (Figure 25A).

The flow from the absorbers passed from the absorber discharge tubes into a 26-inch diameter tail-water tank and then into the discharge line leading to the tailrace (Figure 4). Pressure measurements were made at the bypass valve inlet (Station 1) and at suitable stations in the absorbers. Flow measurements were made with an 18-inch venturi meter. The velocity distribution at the exit of the absorber discharge tubes was determined by impact-tube traverses at the station shown in Figure 4. Air traps were effectively employed to keep the gage lines free of air and full of water.

Pelton Energy Absorber

In addition to the piezometer ring at the inlet valve entrance, piezometer rings were provided in the elbow of the discharge section just below the bowl and near the outlet of the discharge tube (Stations 2 and 3, Figures 4 and 21). The back pressure on the system, as controlled by the 16-inch butterfly valve and the 6-inch air inlet on the discharge line to the tailrace, was measured in the turbine draft tube tank (Station 4, Figure 21).

A great deal of noise and vibration were present when the absorber was operated, the greatest intensity of vibration being at the inlet to the discharge elbow. The inlet valve was opened by 1/4-inch increments, and data were taken at each point. The maximum opening considered safe during the tests was 2-1/4 inches, at which a flow of about 20 cfs was obtained. The relation of rate of flow to valve opening for the model absorber, when operating at a constant total head of 500 feet, is shown in Figure 23E. Tests were made both with and without air admission. The manufacturer stipulates that air must be supplied in prototype units. The amount of air admitted to the model was adjusted to be just sufficient to quiet the cavitation, as evidenced by the sound and vibration of the system. The piezometric pressures are given in Figure 23, A and B, and the air required for quieting cavitation is given in Figure 23C. It should be noted that at valve openings larger than 30 percent of the seat diameter (an opening of 1.5 inches in this case), the air inlet could not supply enough air to fully quiet the cavitation. During removal of the absorbers from the rig, it was discovered that the air holes in the spool below the valve were partly covered by the gasket. Later tests made with the gasket cut out to fully clear the air openings showed the same air deficiency.

The velocity distribution at the outlet of the discharge tube, as determined by impact-tube traverses and observation, is shown in Figure 23D. The location of the traverses and the dimensions of the impact tubes used (Impact Tube No. 2) are shown in Figure 27. The top of the conduit was filled with a foamy air-water mixture, while the lower four-fifths carried the main flow of water. The velocity distribution was poor, with a region of very high velocity in the lower lefthand corner as viewed looking downstream.

After the absorber had been operated about 2 hours under various valve openings, with and without air, it was removed and disassembled for inspection. Much of the paint and some scale had been removed from the baffle and bowl and at the discharge tube entrance, but there was no evidence of cavitation damage to the metal (Figure 22). A much longer test would be required to show cavitation damage, if any damage were to occur.

Three-stage Energy Absorber

The first run was made with air admitted below Stage 1 and with no air admitted below Stage 3. So much noise and vibration occurred and there was such violent "breathing" of the discharge tube that it was considered unsafe to operate at valve openings greater than 1-1/2 inches. In later tests when air was admitted to the third stage, the valve opening was increased to 2-1/4 inches.

The pressure distribution curves, as determined from the piezometer readings, show a wide variation in pressures depending upon the control area of the second stage (Figure 26A). Extreme negative pressures occurred in the region of Station 2 when the inlet valve was first opened, and air was required to reduce the cavitation. At larger openings the negative pressure changed to a positive pressure. This change occurred at 0.6-inch valve opening for the minimum second-stage area of 20 square inches and at 0.9-inch opening for the maximum second-stage area of 50 square inches. As the valve was opened more, the pressure became strongly positive and there was danger of rupturing the lightly built air inlet manifold. It was therefore necessary to block off the inlet manifold with a blind flange, which prevented air being admitted below the first stage.

The pressure at Station 4 was negative at valve openings between 0 and 1/2 inch and was positive at valve openings greater than 1/2 inch, regardless of the second-stage area. The maximum negative pressure measured was 24 feet of water. The pressure at Station 5 decreased with a reduction of area in the second stage, and with an area of 20 square inches the pressure was -20 feet for valve openings of 1-1/2 to 2-1/4 inches. At Stations 2, 6, and 8 the pressures were consistently positive. The head loss curves show the apportionment of the losses through the respective stages (Figure 26B). A reduction in the second-stage area for a given discharge decreases the loss from the inlet to the second stage and increases the loss from the second stage to the third stage. The loss from the third stage to the discharge tube outlet is constant because the third-stage area remained fixed. The amount that the second-stage area affects the discharge is shown on Figure 26D.

The velocity distribution at the absorber outlet, without air being admitted at the third stage, was better than the distribution with the Pelton absorber with air admission (Figure 26C). The flow distribution patterns for the two absorbers cannot be directly compared because they were obtained for different valve openings and discharges. The 3-stage absorber was operated at the maximum valve opening considered safe without air admission to the third stage, or 1-1/4 inches. The Pelton absorber tests, which were completed prior to the 3-stage tests, were made with a valve opening of 1-1/2 inches and with air admission into the absorber. When air was admitted to the third stage of the 3-stage absorber so that the valve could be safely opened to 1-1/2 inches, the jet from the orifice continued through the discharge tube without appreciable expansion or diffusion. No data were taken for this condition because the instrumentation was not of sufficient capacity or strength to withstand the high velocity jet.

Definite evidence of cavitation damage was found when the model was disassembled after about 2 hours of operation. Metal had been removed in an annular ring on the inside of the outer sleeve just above the bottom flange, and on the inner tube supports and the inner and outer sleeves where the supports were welded (Figure 25). In addition, paint was removed from the inner pipe and at the entrance to the third stage. Paint was also removed from portions of the outside of the inner tube. The paint removal was not considered conclusive evidence of cavitation erosion in these regions, but it suggests that such erosion might occur.

In general, the 3-stage absorber was noisier and vibrated with greater intensity than the Pelton absorber. When air was admitted at the third stage, there seemed to be a small decrease in the violence of these conditions, but there was little or no dissipation of energy within the third stage of the absorber.

COMMENTS

A number of difficulties were encountered during the test program and are enumerated here to serve as a guide in future high head testing.

At first the 18-inch motor-operated valve in the supply line could not be operated because, due to improper tagging in the control room, the electrical lines could not be energized. This was remedied by the plant electrician after he traced the wires from the pump pit to the control room. The valve also gave trouble in that is could not be closed under a high differential head. It was necessary to make all closures by shutting the flow off as much as possible at the models and then closing the 18-inch valve, while the 4 inch bypass remained open. After the 18-inch valve was closed, the bypass was closed. This malfunctioning of the 18-inch valve was corrected after it was pointed out in the field trip report dated February 18, 1952.

Entry into the valve pit was difficult and hazardous because of inadequate handholds and the fact that the open cover had to be grasped in order to reach the ladder rungs (Figure 29A). This difficulty has largely been eliminated by the addition of more handholds.

Shut-off valves were used in the high-pressure gage lines to facilitate bleeding the instruments and to make it possible to remove gage lines where necessary. Unfortunately, the valves used did not come to a stop when fully opened, as is usually the case. As a result, on several occasions early in the test program, the valves were backed out so far that the stems were blown from the body and water at a 250-pound pressure squirted over the personnel and test apparatus. After these dangerous and unpleasant experiences, considerable care was taken to avoid opening the valves too far.

The velocity traverses made at the exits of the energy absorber draft tubes were not anticipated when the test program was planned, but were a last minute decision. As a result, and due to the limited time then available, inadequate preparations were made. A standard laboratory Pitot-static tube was used in the first test (Figure 27). It was damaged almost immediately in the high velocity flow. It was replaced with a cylindrical Pitot-static tube made of 1/2-inch galvanized pipe and supported in a cantilever arrangement by a boss at the left side of the conduit (Impact Tube No. 1, Figure 27). This tube was bent backwards at a 30-degree angle by the flow. The traverses were finally made by using cylindrical-Pitot-static tubes that extended through the passage and were supported in bosses on each side of the conduit (Impact Tube No. 2, Figure 27). Both total head and piezometric head were measured with these tubes, the tubes being rotated in the stream to balance the two static pressure readings, thereby causing the total head opening to face squarely into the stream. The three No. 2 tubes were all in place during the runs and the gage lines were kept free of air by air traps (Figure 27).

The amount of energy released into the draft tube of the 3-stage energy absorber was so great that the draft tube "breathed" violently and began to fail by splitting at the welded seams. It was necessary to repair these breaks and to reinforce the draft tube with bands of channel iron before the testing could continue.

Considerable pressure was built up in the region of the Stage 1 air manifold of the 3-stage absorber when the valve opening reached 1-1/4 inches. This manifold was lightly built and not capable of withstanding heavy internal pressures, and it was necessary to seal it off by a sheet metal ring so that tests could be made at larger valve openings.

The SF-4 turbine runner was received directly from the manufacturer's shops, and it had not been previously assembled on the turbine shaft. When assembly was attempted, it was found that the bore was tapered and oversize and that the seal rings were eccentric. It was necessary to rebuild the bore and the seal rings in the laboratory shops in Denver by building up the sections with metal spray and then remachining to the proper dimensions.

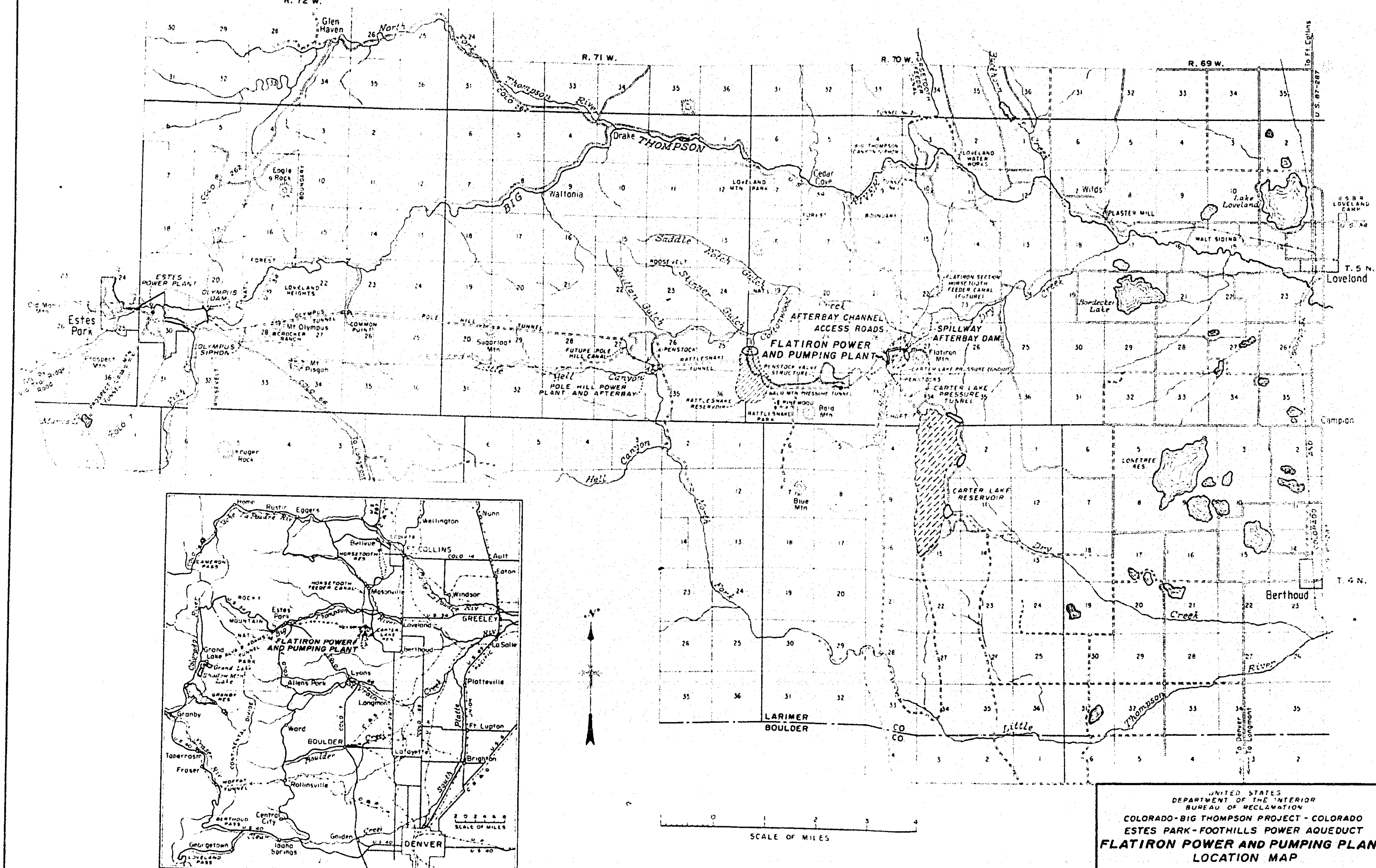
The 1/2-inch-thick transparent plastic spool used by the manufacturer in the low head test to connect the turbine outlet to the draft tube was used for the preliminary tests at Estes Powerplant (Figure 17C). The section ruptured after only a few minutes of testing, and tests were discontinued until the metal spool that had been shipped by the manufacturer arrived at Estes Park. Upon receiving the spool, it was found that no holes had been drilled in the spool flanges, and it was therefore necessary to lay out and drill bolt holes at the proper radius and spacings to match the turbine case and the draft tube inlet.

During the turbine tests, difficulty was experienced in setting the lower speed points at large wicket gate openings because the water brake dynamometer was barely able to handle these high-torque loads. A dynamometer with greater capacity would have greatly facilitated this part of the test program.

The electronic timer and counter had to be moved inside the powerplant during the latter part of the test program because their performance became erratic in the cold, wet atmosphere on the powerplant deck. This considerably increased the difficulty of coordinating the taking of data when the test points were set. The necessary coordination was finally obtained by installing a set of field telephones.

The 16-inch butterfly valve located in the discharge line a few feet above the tailrace caused more trouble and delay in the test program than any other item. The loads that were imposed upon this valve were greatly underestimated, and, as a result, a relatively lightweight valve was installed. Almost every conceivable type of failure occurred on the valve. After the shaft broke, it was replaced with a new shaft of higher quality steel. When the cast iron valve leaf broke a new leaf was made of 1/2-inch boiler plate and a much heavier shaft was installed. This was followed by repeated shearing of the pin which held the worm gear to the shaft. When heavier pins were installed, the teeth of the cast iron worm gear failed. This gear was replaced with a steel one which lasted just long enough so that the tests could be completed. Each time repairs were required, it was necessary to row a boat into the tailrace, remove the valve while working from this boat, and row back down to the dock (Figure 29B). The valve was then transported to the machine shop of the powerplant, where repairs were made. To reinstall the valve, it was necessary to repeat the boat trip. This consumed a great deal of time and entailed considerable risk to the men working from the boat in the powerplant tailrace.

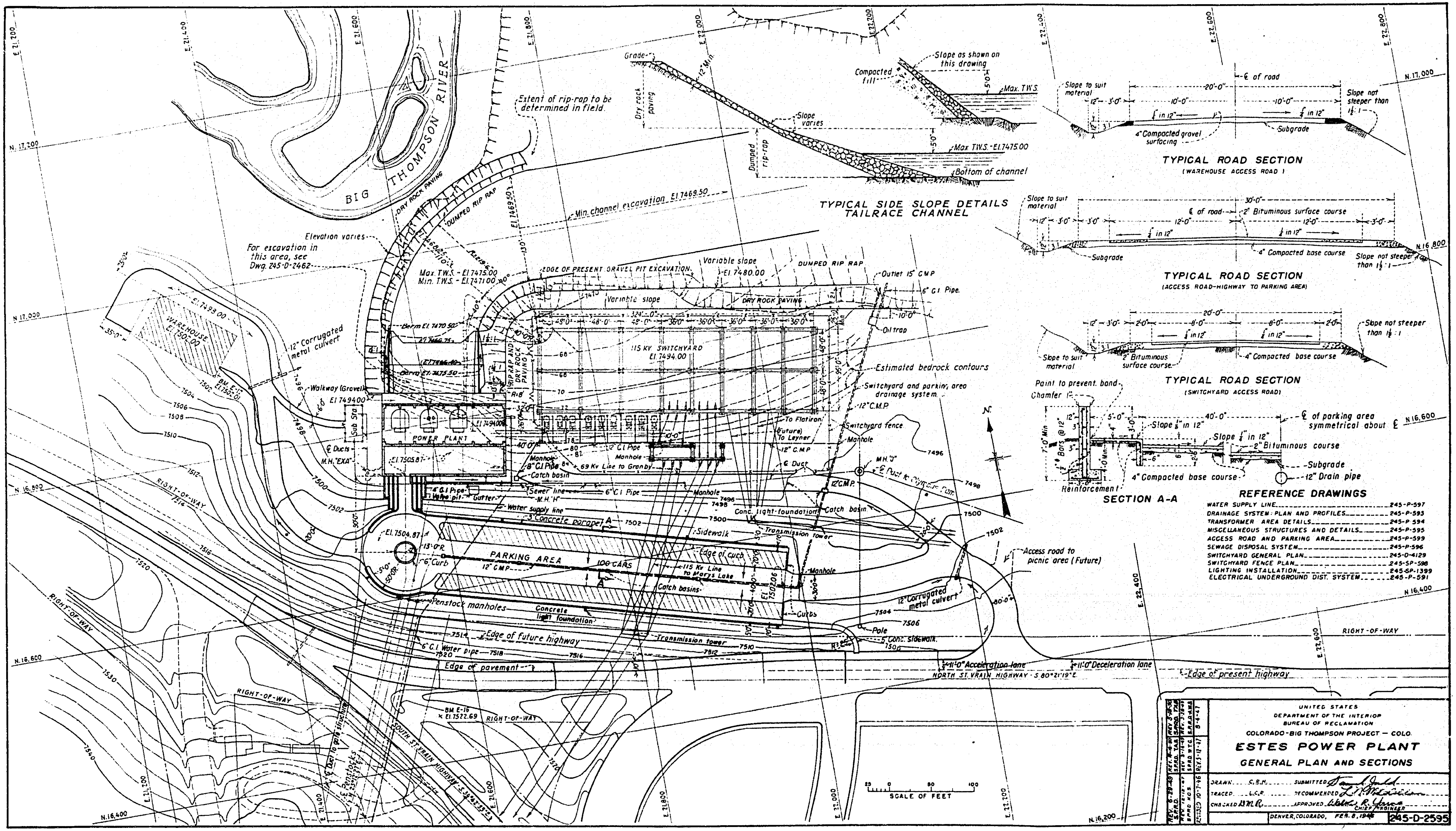
It was anticipated that the testing would be done during the summer, and if so, there would have been no particular trouble from the weather. As it turned out, the testing was not started until late in September and was not completed until the 9th of November. During this time there were several snow storms, considerable freezing weather, and a period of subzero temperatures. To protect the piping and the hydraulic equipment, it was necessary to drain them at the end of each day. The addition of electric heaters in the temporary canvas enclosure around the test equipment did not prevent freezing of the gage lines during operation in the coldest weather. During those times when all reasonable attempts failed to keep the gage lines open, the testing was discontinued and was not resumed until the weather moderated. All of these difficulties added considerably to the time required for completing the tests and to the cost of the program. Any future outdoor tests at the Estes Powerplant should be conducted not later than the end of September.

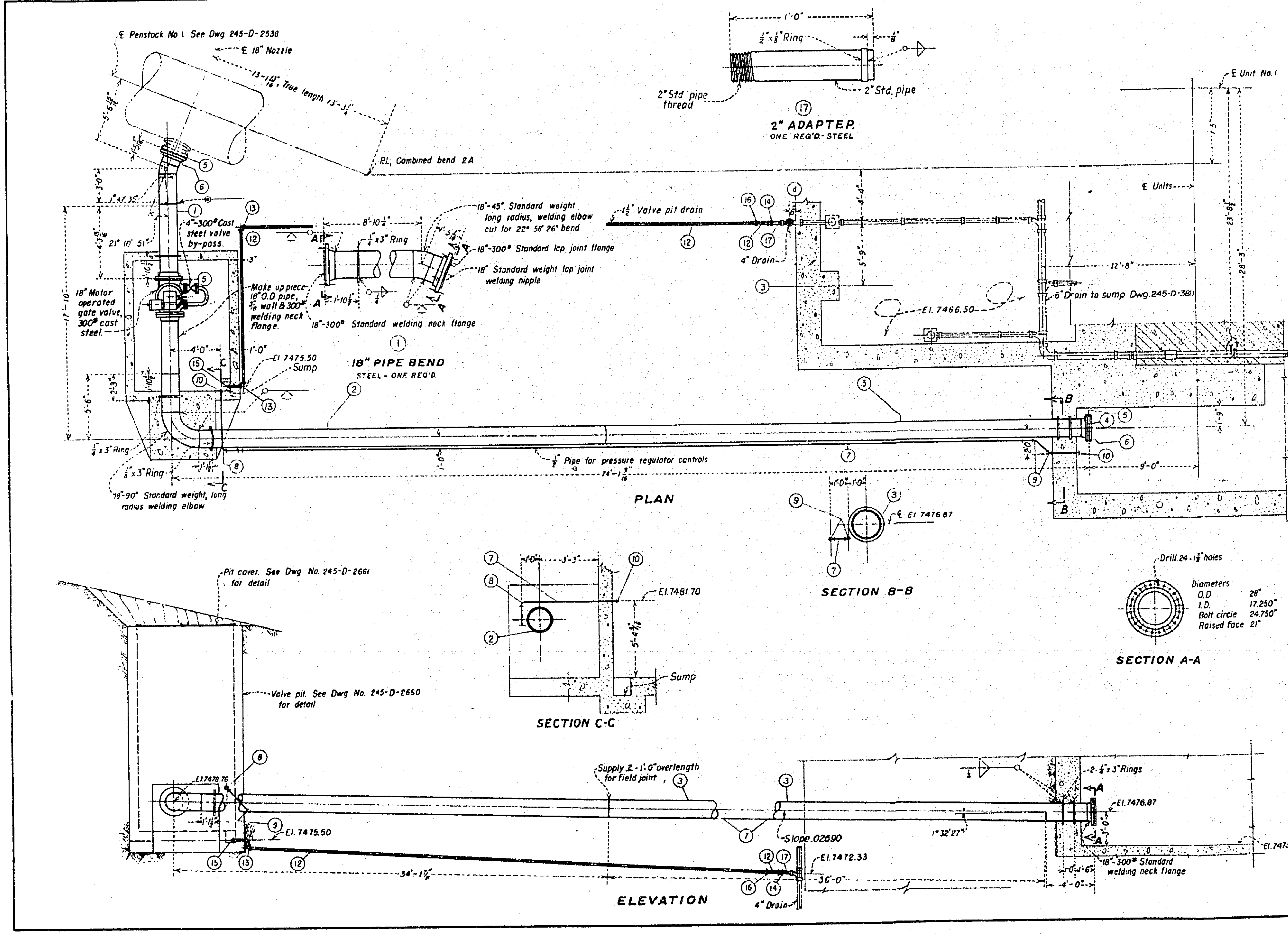


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLORADO
ESTES PARK-FOOTHILLS POWER AQUEDUCT
FLATIRON POWER AND PUMPING PLANT
LOCATION MAP

DRAWN R.E.M. SUBMITTED
TRACED B.F.W. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER

DENVER, COLORADO - NOV. 7, 1950 245-D-5890


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT — COLO.
ESTES POWER PLANT
GENERAL PLAN AND SECTIONS
DENVER, COLORADO, FEB. 8, 1946
245-D-2595
TYPICAL SIDE SLOPE DETAILS
TAILRACE CHANNEL
Slope as shown on this drawing
Compacted fill
Max. T.W.S.
Grade
Dry rock paving
Slope varies
Dumped rip-rap
Max T.W.S.-El. 7475.00
Bottom of channel
TYPICAL ROAD SECTION
(WAREHOUSE ACCESS ROAD)
Slope to suit material
Slope not steeper than 1½:1
4" Compacted gravel surfacing
Subgrade
TYPICAL ROAD SECTION
(ACCESS ROAD-HIGHWAY TO PARKING AREA)
2" Bituminous surface course
4" Compacted base course
TYPICAL ROAD SECTION
(SWITCHYARD ACCESS ROAD)
2" Bituminous surface course
SECTION A-A
℄ of parking area symmetrical about ℄
2" Bituminous course
12" Drain pipe
4" Compacted base course
Reinforcement
REFERENCE DRAWINGS
WATER SUPPLY LINE 245-P-597
DRAINAGE SYSTEM: PLAN AND PROFILES 245-P-593
TRANSFORMER AREA DETAILS 245-P-594
MISCELLANEOUS STRUCTURES AND DETAILS 245-P-595
ACCESS ROAD AND PARKING AREA 245-P-599
SEWAGE DISPOSAL SYSTEM 245-P-596
SWITCHYARD GENERAL PLAN 245-D-4129
SWITCHYARD FENCE PLAN 245-SP-596
LIGHTING INSTALLATION 245-SP-1399
ELECTRICAL UNDERGROUND DIST. SYSTEM 245-P-591
BIG THOMPSON RIVER
Extent of rip-rap to be determined in field.
Min. channel excavation El. 7469.50
WAREHOUSE El. 7493.00
115 KV SWITCHYARD El. 7494.00
POWER PLANT
Sub Sta
PARKING AREA
100 CARS
Edge of future highway
Edge of pavement
NORTH ST. VRAIN HIGHWAY
SOUTH ST. VRAIN HIGHWAY
Edge of present highway
11'-0" Acceleration lane
11'-0" Deceleration lane
RIGHT-OF-WAY
Access road to picnic area (Future)
SCALE OF FEET



LIST OF PARTS

PART NO.	DESCRIPTION	MATERIAL	NO. REQ'D.
1	18" Pipe bend	Steel	1
2	18" Pipe bend	Steel	1
3	18" Pipe bend	Steel	1
4	18"-300# Blind flange	Steel	2
5	17" I.D. x $23\frac{1}{2}$" x $\frac{1}{16}$" ring gasket	Asbestos composition	3
6	$1\frac{1}{4}$" x $6\frac{1}{2}$" Square head machine bolt with hex. nut	Steel	72
7	$\frac{1}{2}$" Standard pipe, threaded and coupled, random lengths	Steel, galvanized	87'-0"
8	$\frac{1}{2}$"-90°-150# Std. screwed elbow	Malleable iron, galv.	1
9	$\frac{1}{2}$"-45°-150# Std. screwed elbow	Malleable iron, galv.	3
10	$\frac{1}{2}$"-150# Std. pipe cap	Malleable iron, galv.	2
11	$\frac{1}{2}$"-300# Std screwed female union, ground joint, brass to iron seats	Malleable iron, galv.	4
12	$1\frac{1}{2}$" Standard pipe, threaded and coupled, random lengths	Steel	91'-0"
13	$1\frac{1}{2}$"-90°-150# Std. screwed elbow	Malleable iron, galv.	2
14	2" x $1\frac{1}{2}$"-150# Std. screwed reducer	Malleable iron, galv.	1
15	$1\frac{1}{2}$"-150# Std. pipe cap	Malleable iron, galv.	1
16	$1\frac{1}{2}$"-150# Std. screwed female union, ground joint, brass to iron seats	Malleable iron, galv.	1
17	2" Adapter - see detail	Steel	1
18	$1\frac{1}{2}$"-90°-150# Std screwed elbow	Malleable iron, galv.	1

Parts Nos. 1 to 17 incl. were procured under invitation No. F 46,185-A
Part No 18 is to be furnished by the project.
Make-up piece furnished under invitation No SP-3025
18" Motor operated gate valve and by-pass furnished under invitation No. G-46,396-A.

NOTE

Parts 1, 2, and 3 are to be made from 18" O.D pipe with $\frac{1}{2}$" wall.

REFERENCE DRAWINGS

78" PENSTOCKS 245-D-2538
VALVE PIT 245-D-2560
VALVE PIT COVER AND LADDER RUNGS 245-D-2661

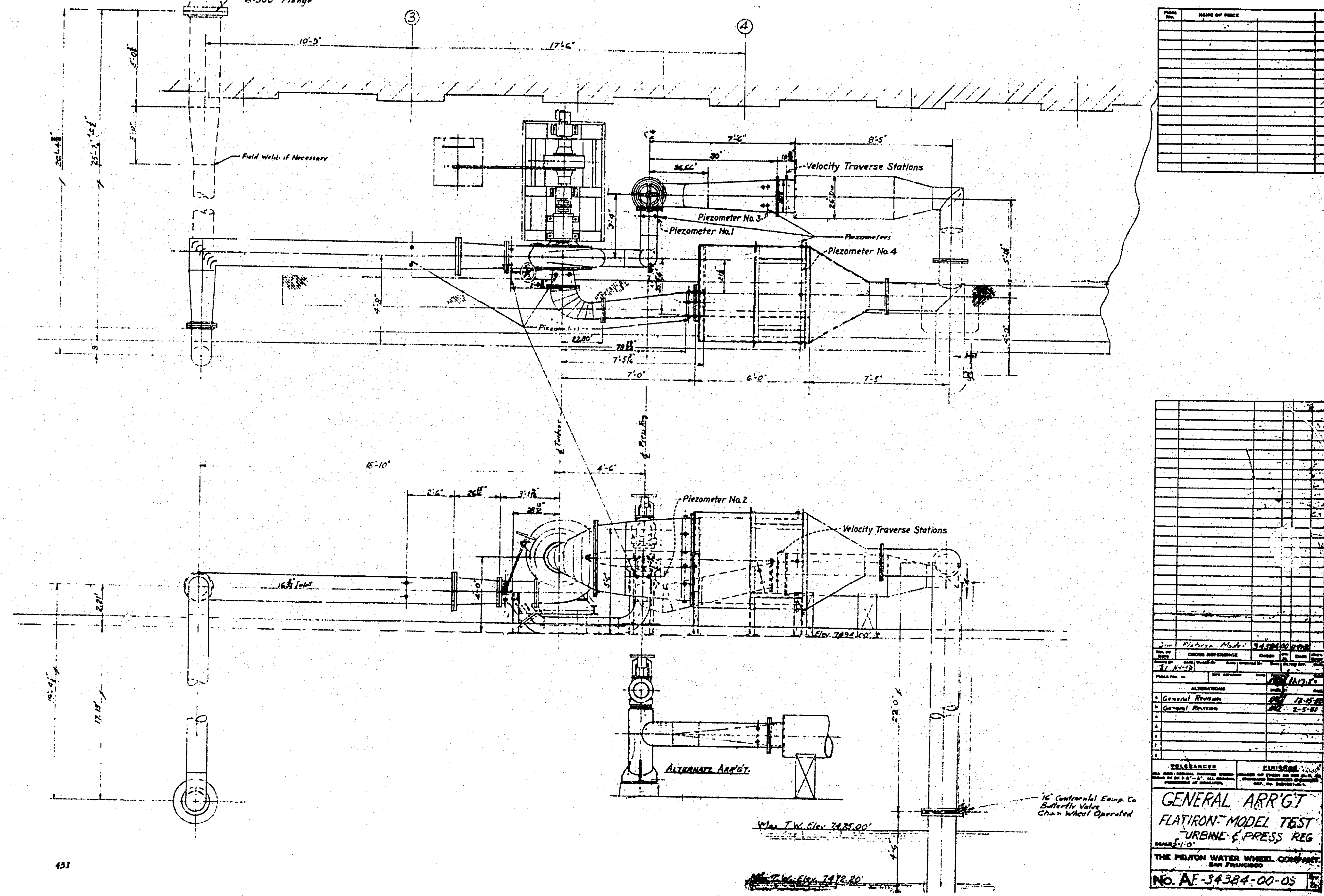
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLO.

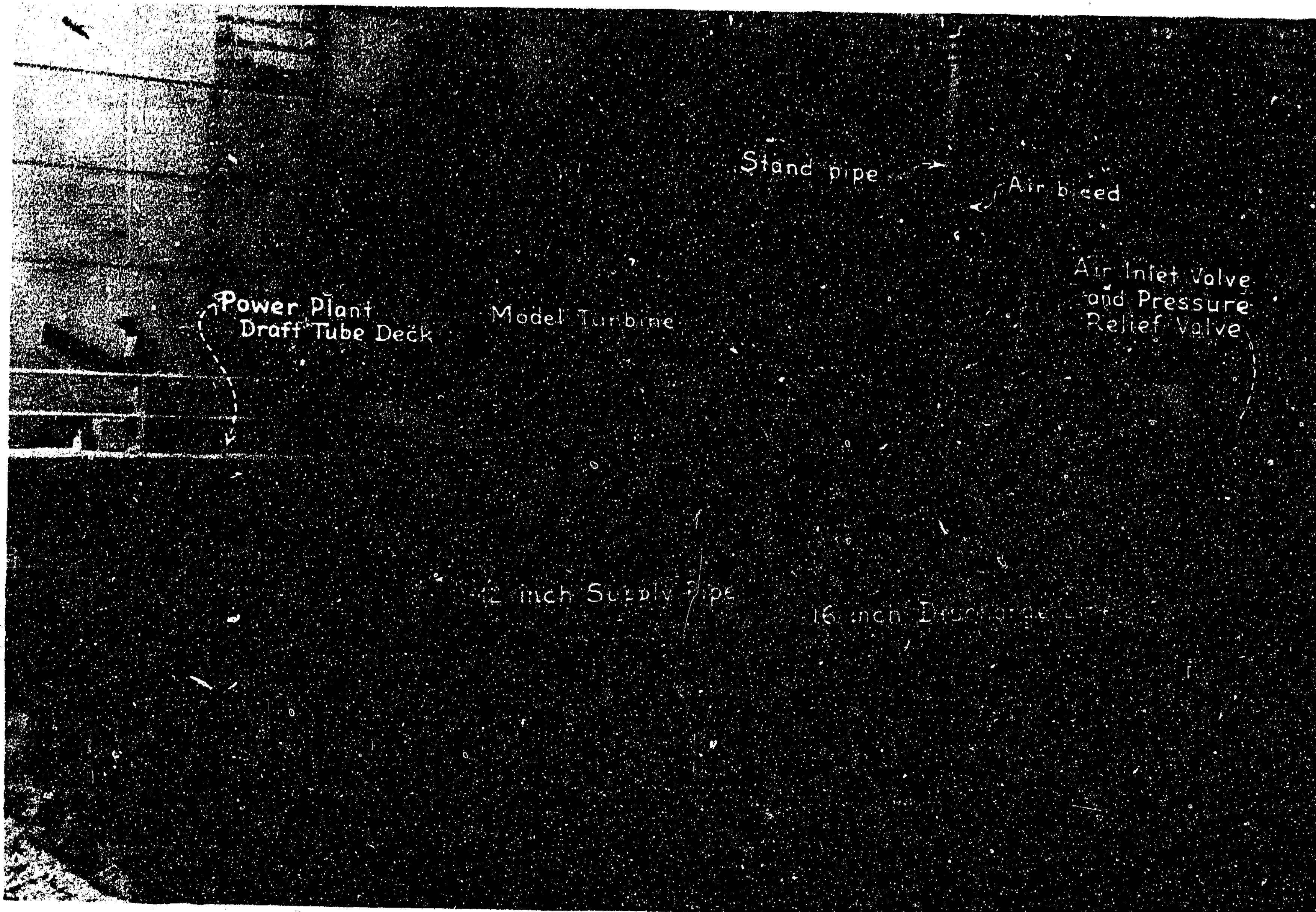
ESTES POWER PLANT
78" PENSTOCK
18" HIGH-HEAD LABORATORY OUTLET
PLAN AND ELEVATION

DRAWN T.R.P. SUBMITTED
TRACED J.S. ~ V.F.S. RECOMMENDED
CHECKED L.L.A. T.H. APPROVED ASS'T CHIEF ENGINEER
DENVER, COLORADO, FEB. 27, 1946
245-D-2659

REV. 10-25-50 | REV. 6-20-47 | REV. 8-1-48 | 7-15-47 | 11-29-46 | 10-19-50 | 5-7-47

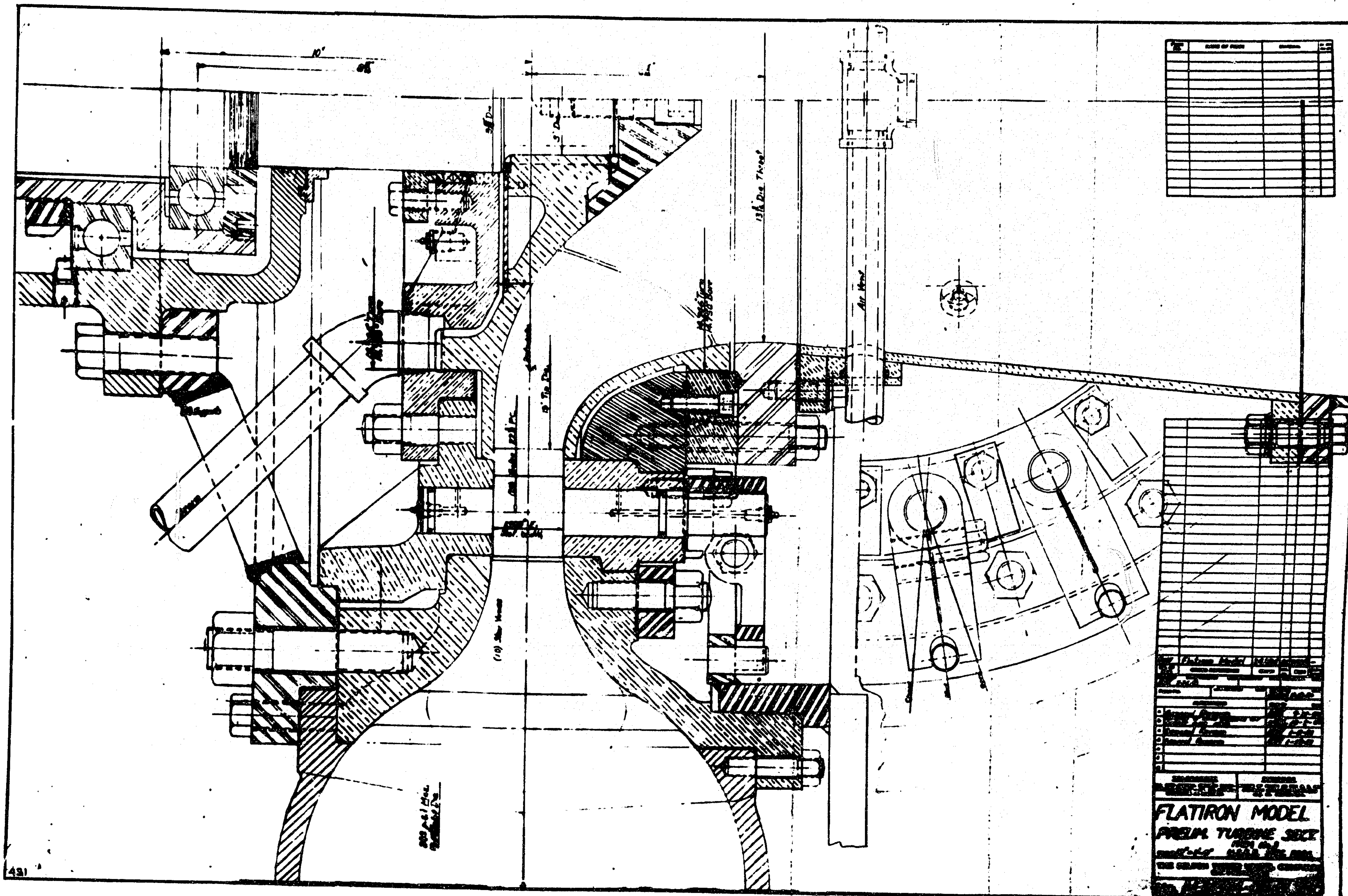
FIGURE 4
REPORT HYD. 348





HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER
Test equipment installed on deck of Estes Power Plant.

FIGURE 8
Report Hyd. 348


FLATIRON MODEL
PRELIM. TURBINE SECT.
10"
Air Vent
431

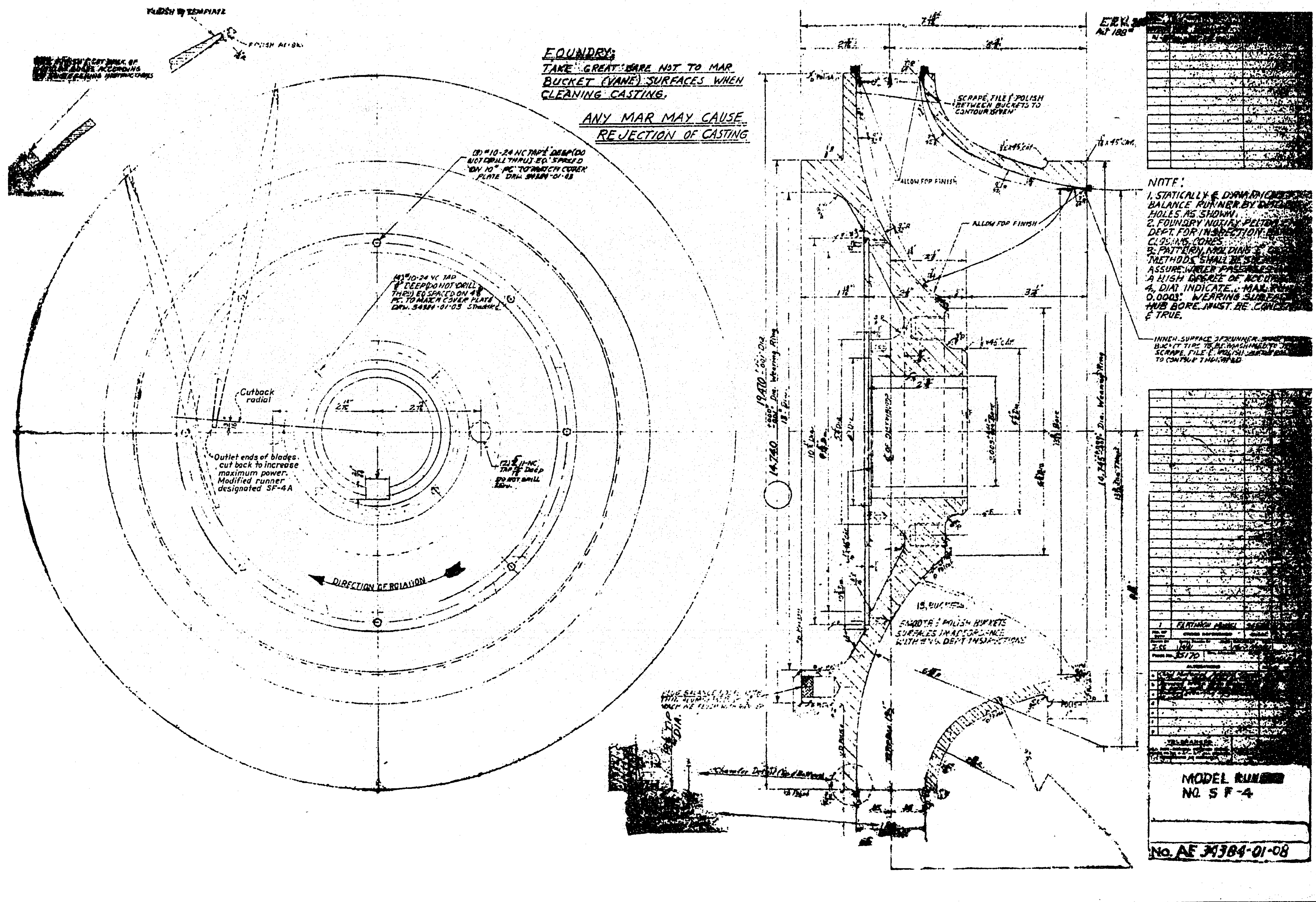
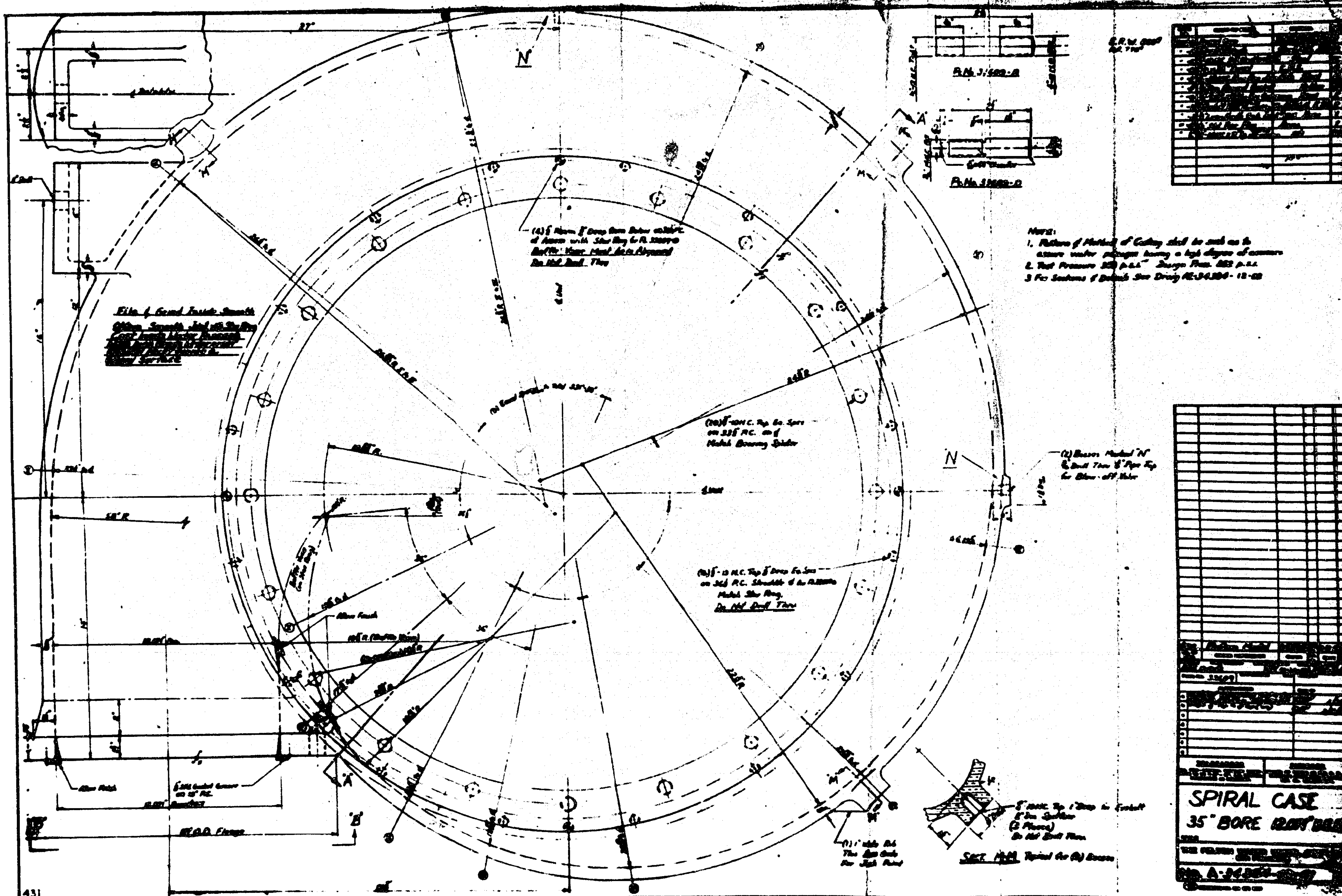
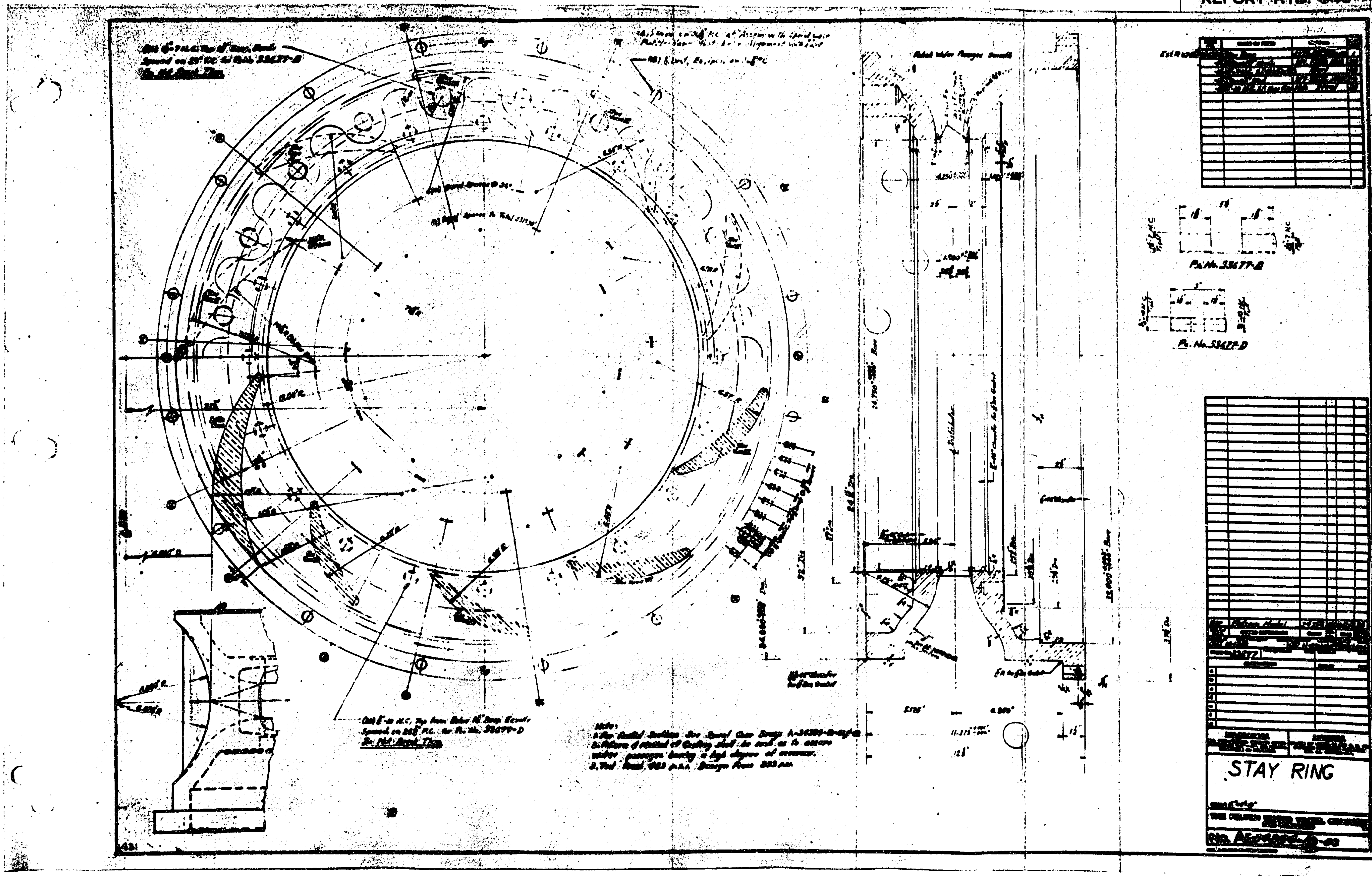
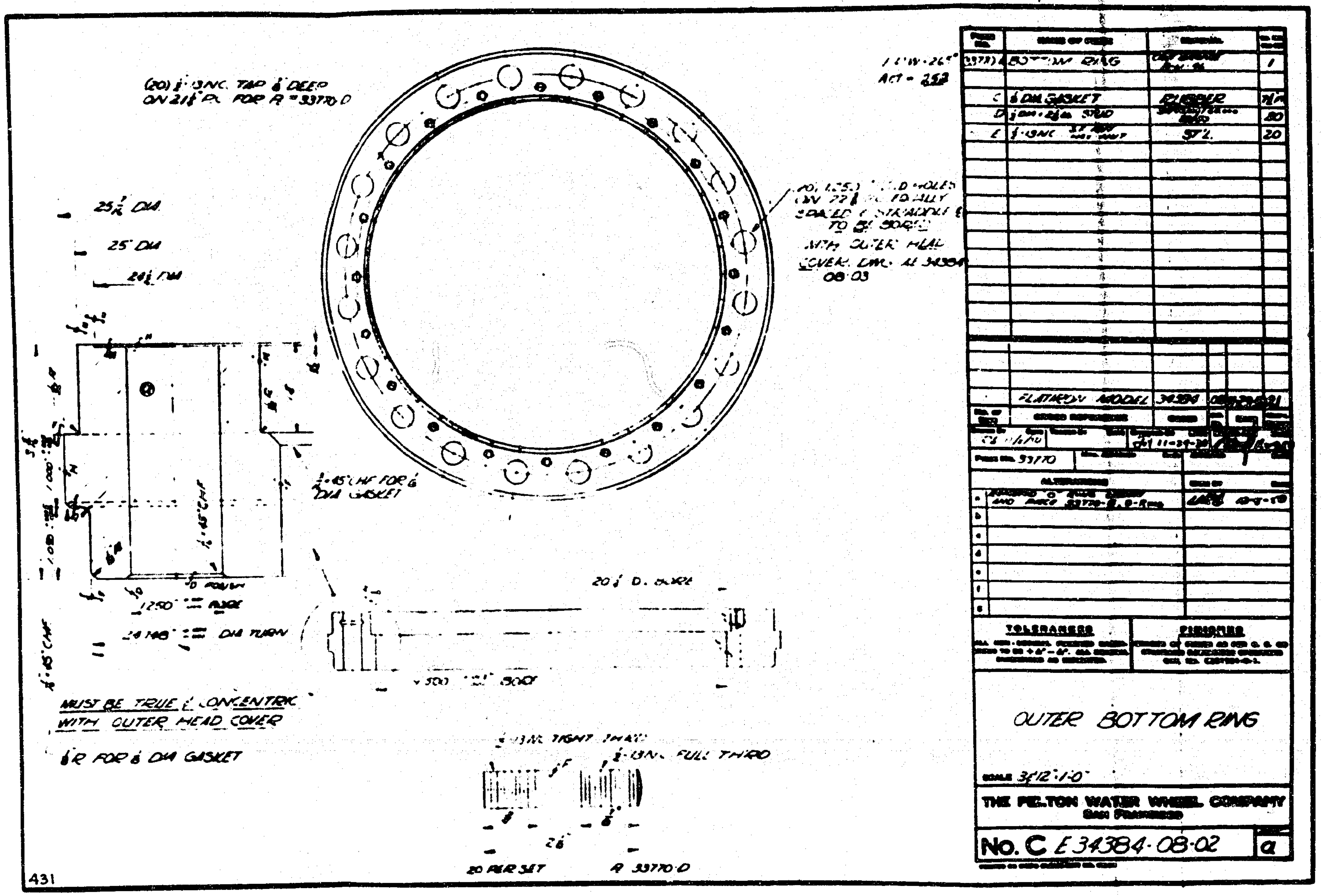
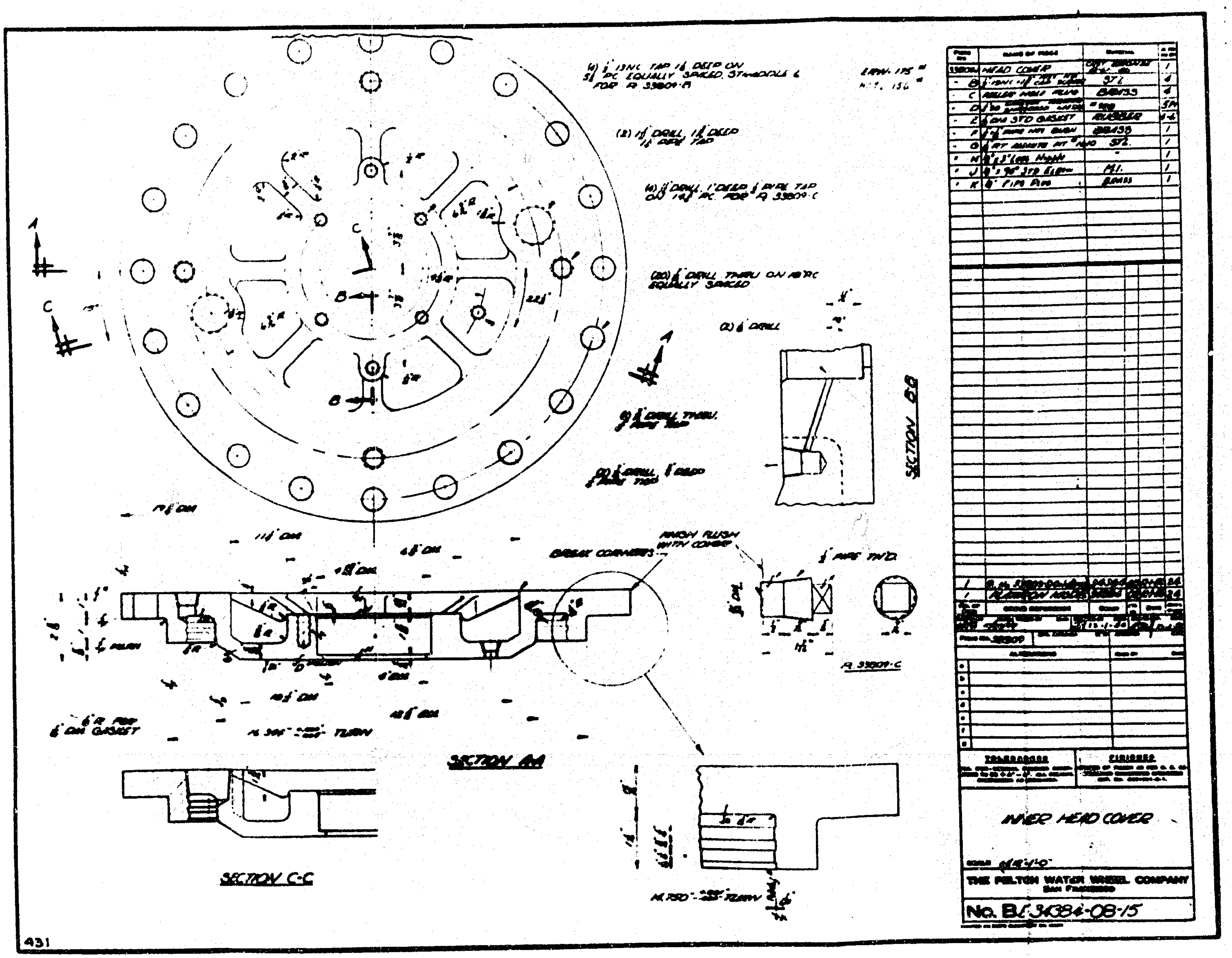

FOUNDRY:
TAKE GREAT CARE NOT TO MAR BUCKET (VANE) SURFACES WHEN CLEANING CASTING.
ANY MAR MAY CAUSE REJECTION OF CASTING
Cutback radial
Outlet ends of blades cut back to increase maximum power. Modified runner designated SF-4A
DIRECTION OF ROTATION
NOTE:
ALLOW FOR FINISH
15 BUCKETS
MODEL
NO. S F-4
No. AE 34384-01-08

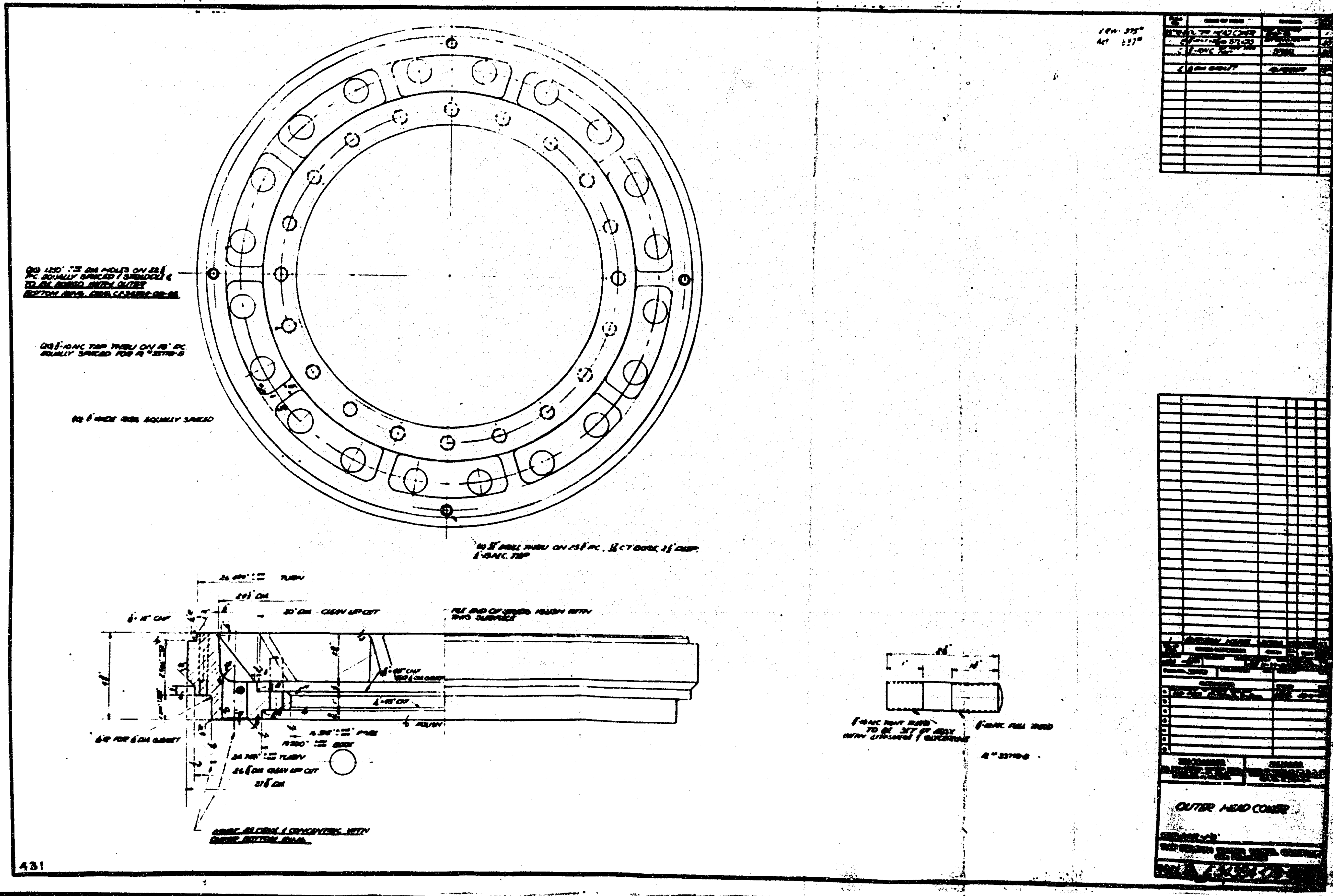
FIGURE 8
REPORT HYD. 348

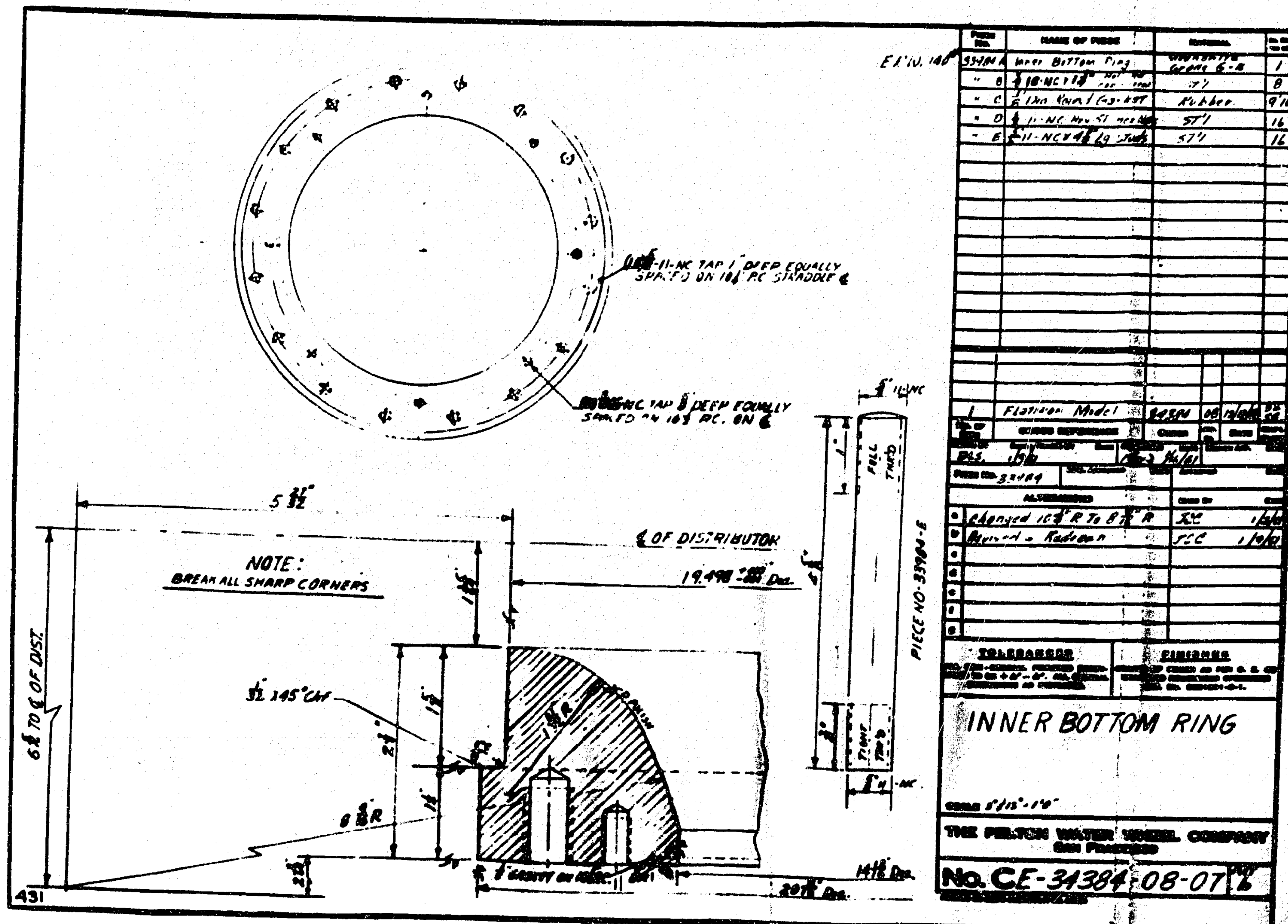



STAY RING


OUTER BOTTOM RING
THE PELTON WATER WHEEL COMPANY
San Francisco
No. C E 34384-08-02
FLATIRON MODEL
MUST BE TRUE & CONCENTRIC
WITH OUTER HEAD COVER
25 DIA
20 PER SET
TOLERANCES
FINISHES
431


SECTION A-A
SECTION B-B
SECTION C-C
INNER HEAD COVER
THE PELTON WATER WHEEL COMPANY
No. BE 34384-08-15


OUTER HEAD COVER


NOTE:
BREAK ALL SHARP CORNERS
INNER BOTTOM RING
THE PELTON WATER WHEEL COMPANY
SAN FRANCISCO
No. CE-34384-08-07
Flatiron Model
C OF DISTRIBUTOR
PIECE NO-33984-E
431

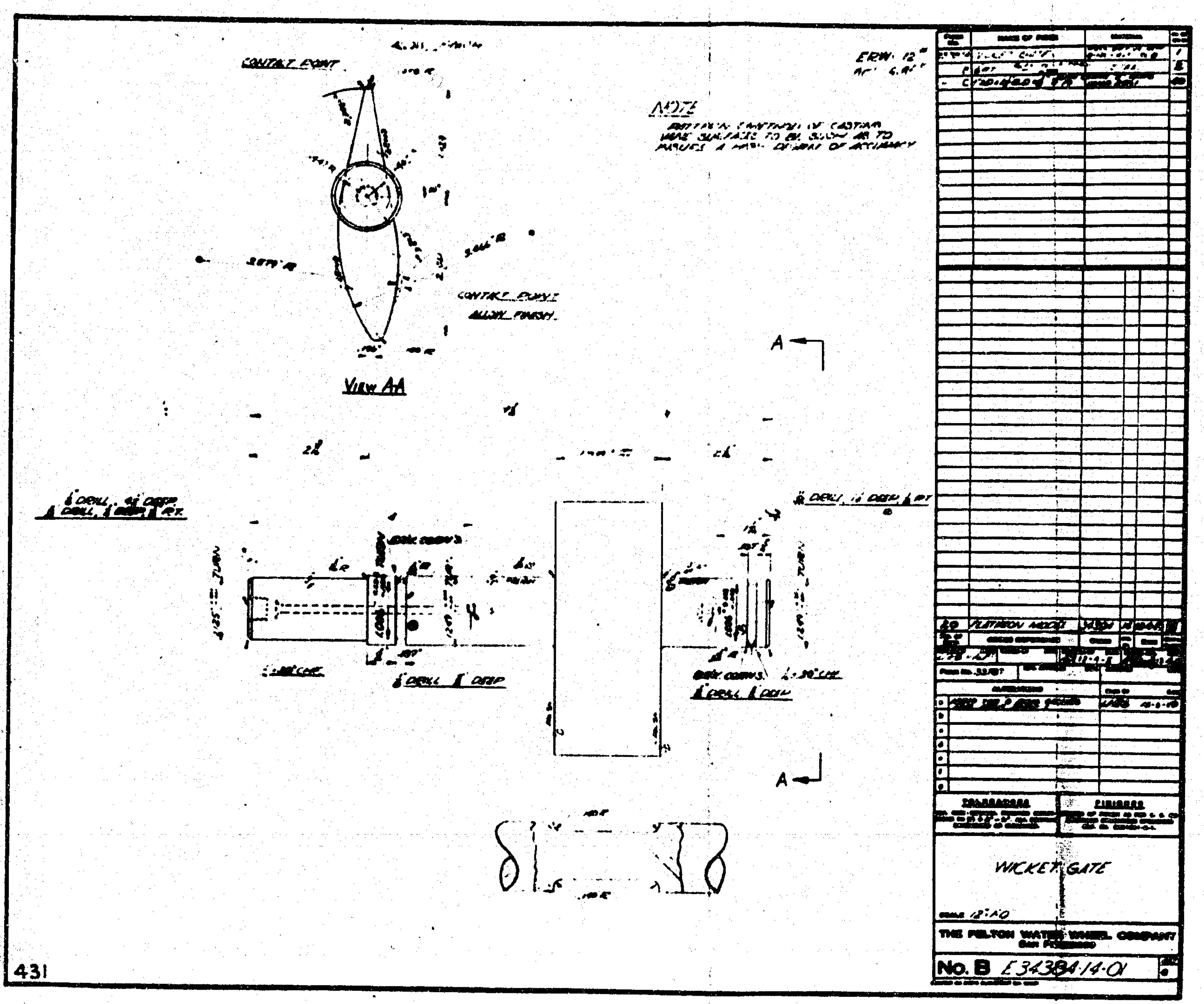
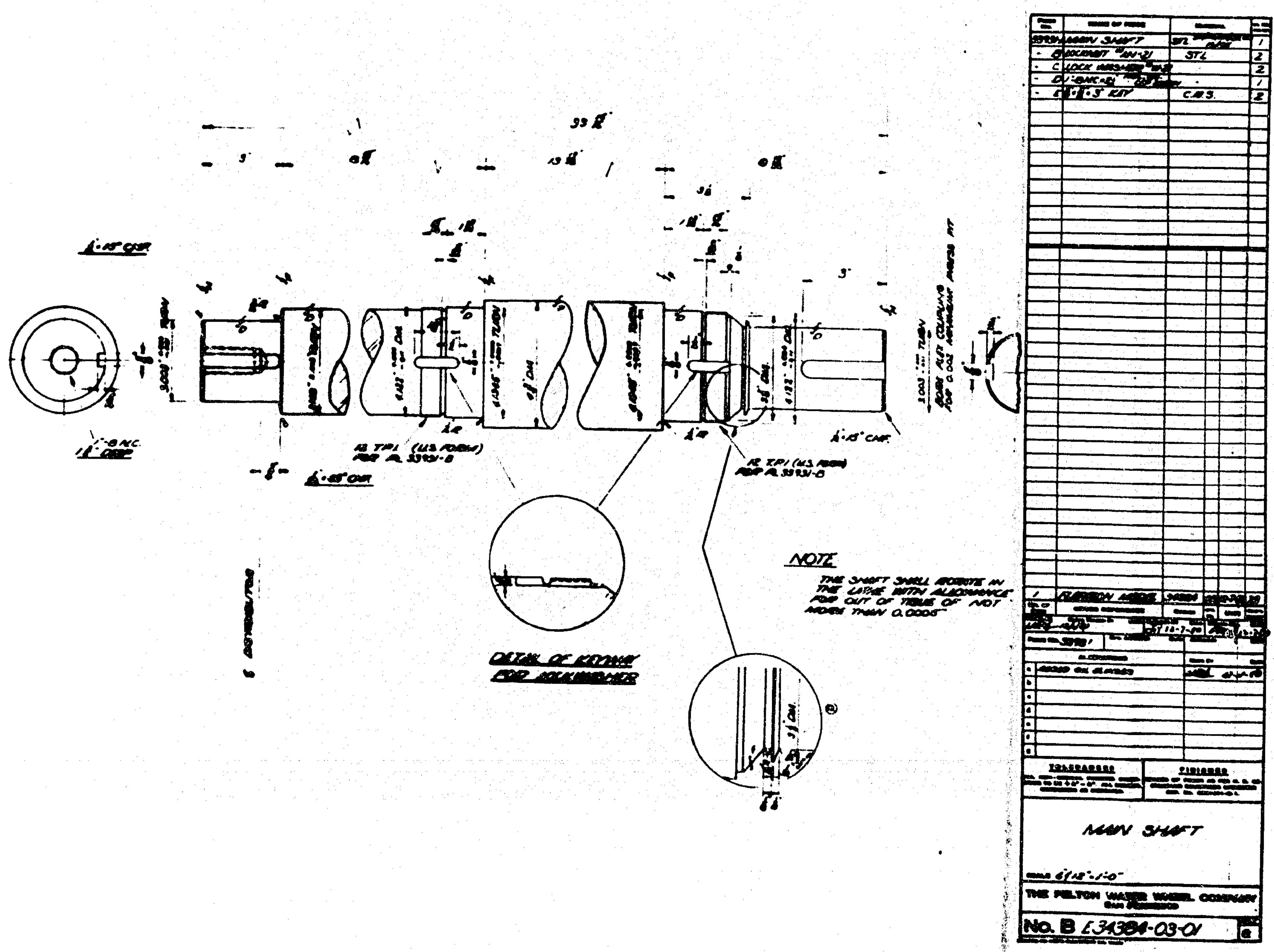
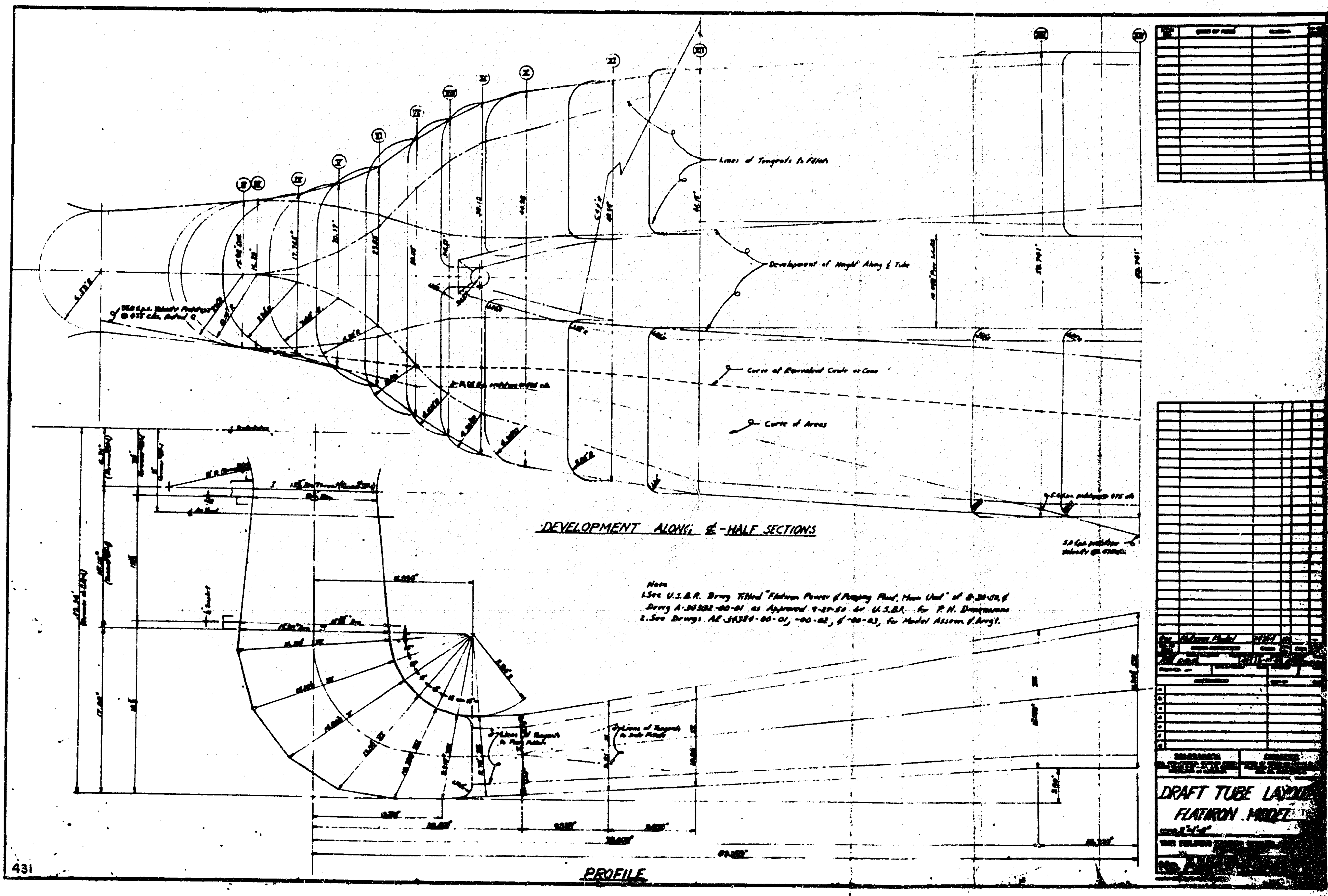
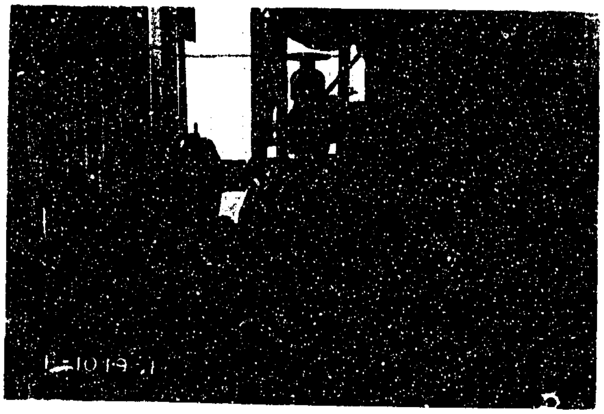

CONTACT POINT
VIEW AA
NOTE
CONTACT POINT
ALLOW FINISH
WICKET GATE
THE PELTON WATER WHEEL COMPANY
SAN FRANCISCO
No. B E34384-14-01

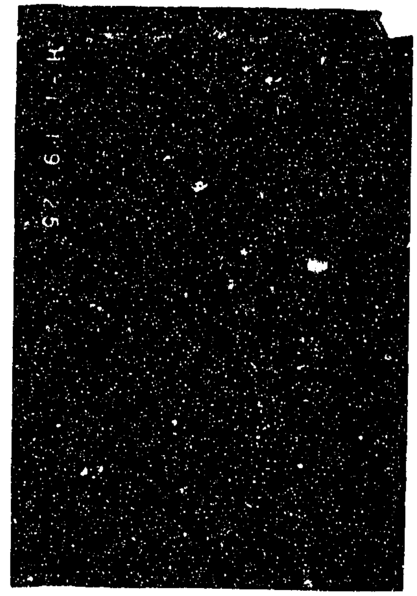
FIGURE 15
REPORT HYD. 348



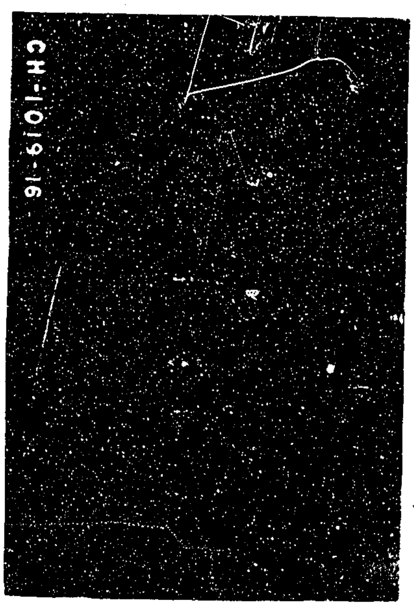

Lines of Tangents to Fillets
Development of Height Along ℄ Tube
Curve of Equivalent Circle or Cone
Curve of Areas
DEVELOPMENT ALONG ℄ - HALF SECTIONS
Note
1. See U.S.B.R. Drwg. Titled "Flatiron Power & Pumping Plant, Main Unit" of 8-29-50, & Drwg. A-30282-00-01 as Approved 9-21-50 by U.S.B.R. for P.H. Dimensions
2. See Drwgs. AE-34384-00-01, -00-02, & -00-03, for Model Assem. & Arrgt.
Lines of Tangents to Floor Fillets
Lines of Tangents to Side Fillets
PROFILE
DRAFT TUBE LAYOUT
FLATIRON MODEL



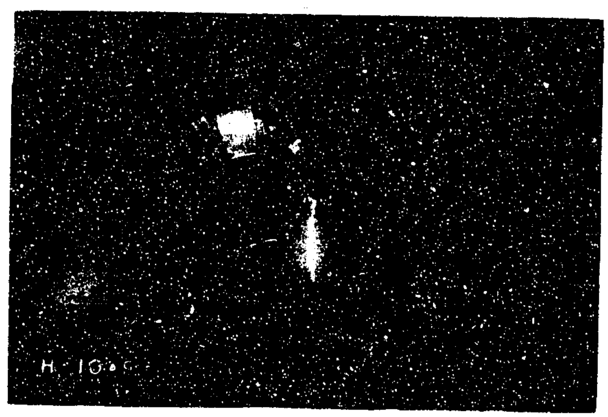
A. Turbine test arrangement. Water Brake dynamometer at left rear, penstock in foreground, and draft tube at right. Spool from turbine to draft tube not installed.



B. Wicket gate assembly, runner removed.



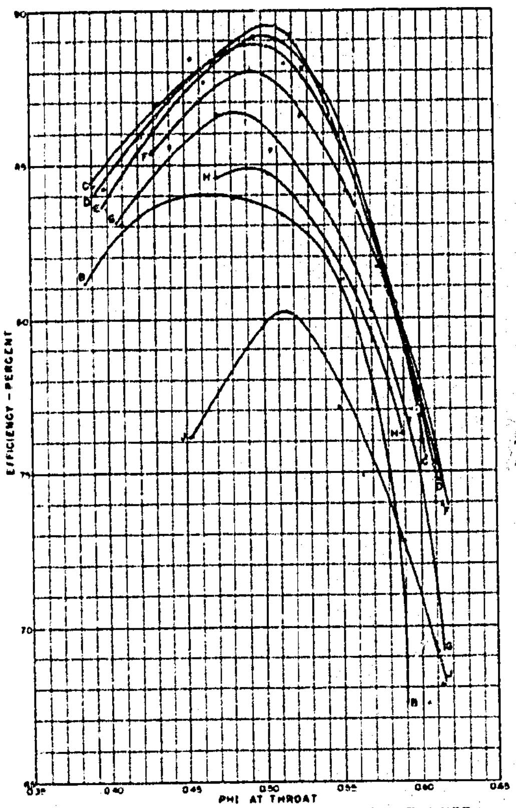
C. Wicket gate assembly with runner and spool to draft tube installed. This spool was replaced by a steel spool when the 1/2-inch thick plastic shattered. Pipe for admitting air into draft tube is shown.



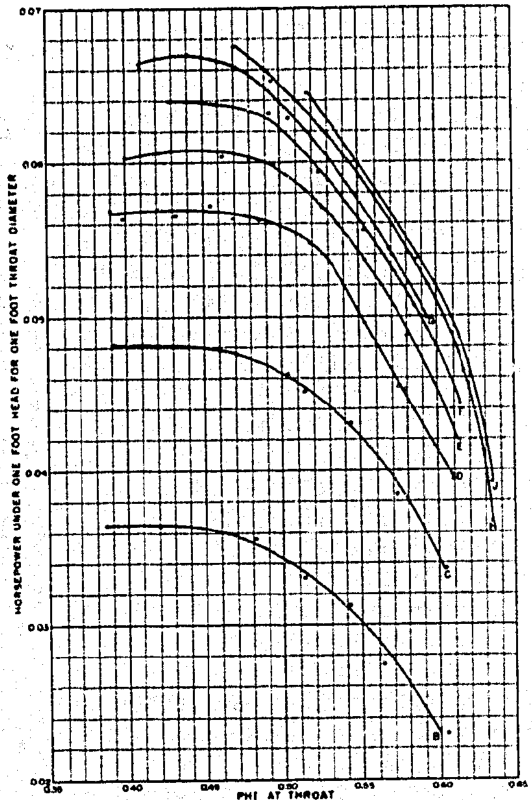
D. SF-1 turbine runner

HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER

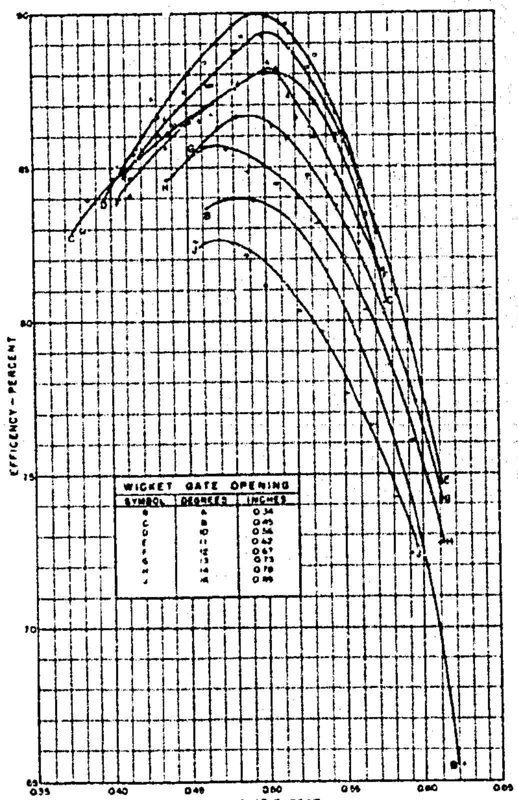
Model Turbine
1:4.21 scale model



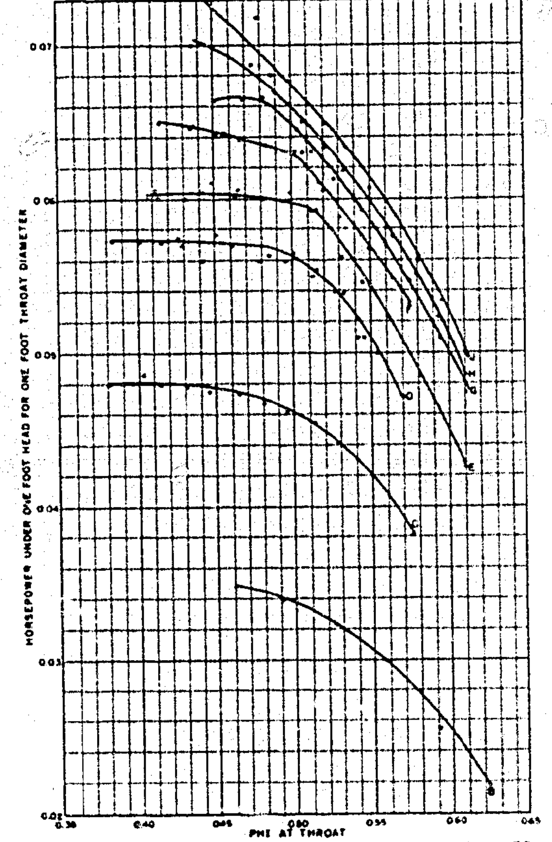
A-EFFICIENCY CURVES - ORIGINAL SF-4 RUNNER



B-UNIT HORSEPOWER CURVES - ORIGINAL SF-4 RUNNER



C-EFFICIENCY CURVES - MODIFIED SF-4 RUNNER

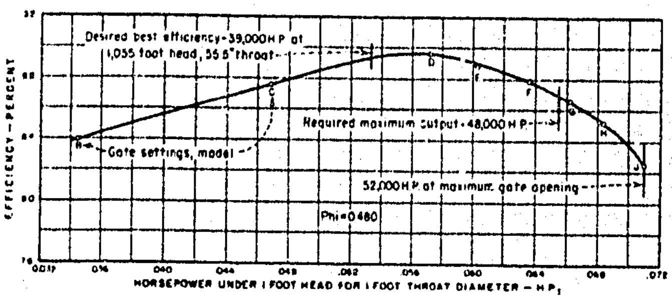


D-UNIT HORSEPOWER CURVES - MODIFIED SF-4 RUNNER

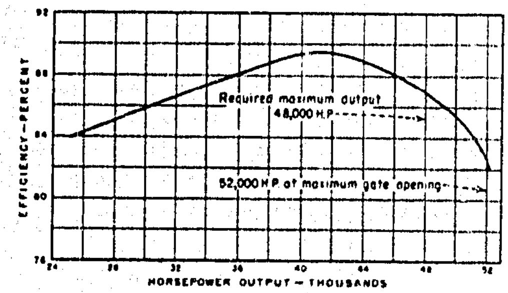
HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER

PERFORMANCE CURVES OF SF-4 AND SF-4A RUNNERS

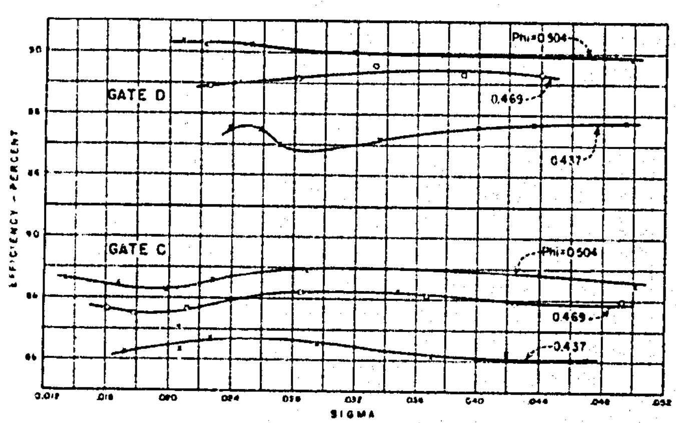
DATA FROM 1:4.21 SCALE MODEL



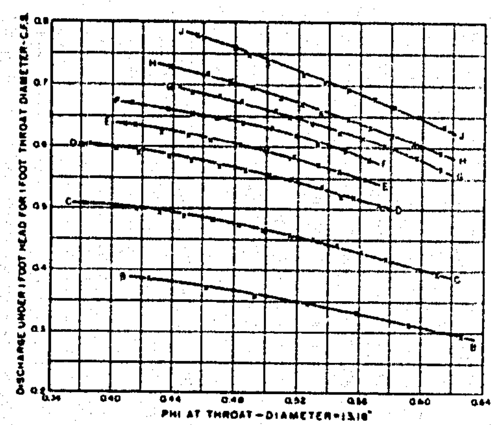
A—UNIT HORSEPOWER VS EFFICIENCY



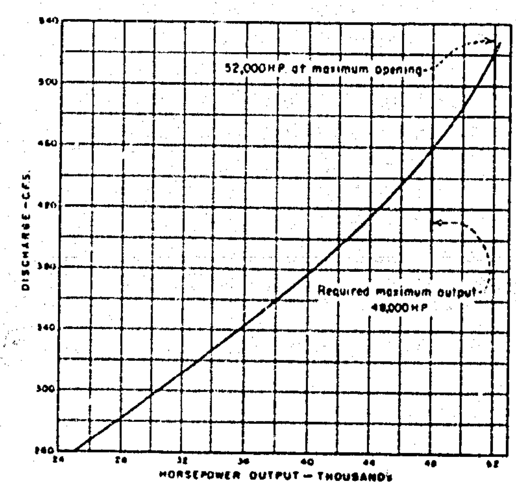
B—TOTAL HORSEPOWER VS EXPECTED EFFICIENCY



C—SIGMA VS EFFICIENCY



D—PHI AT THROAT VS UNIT DISCHARGE



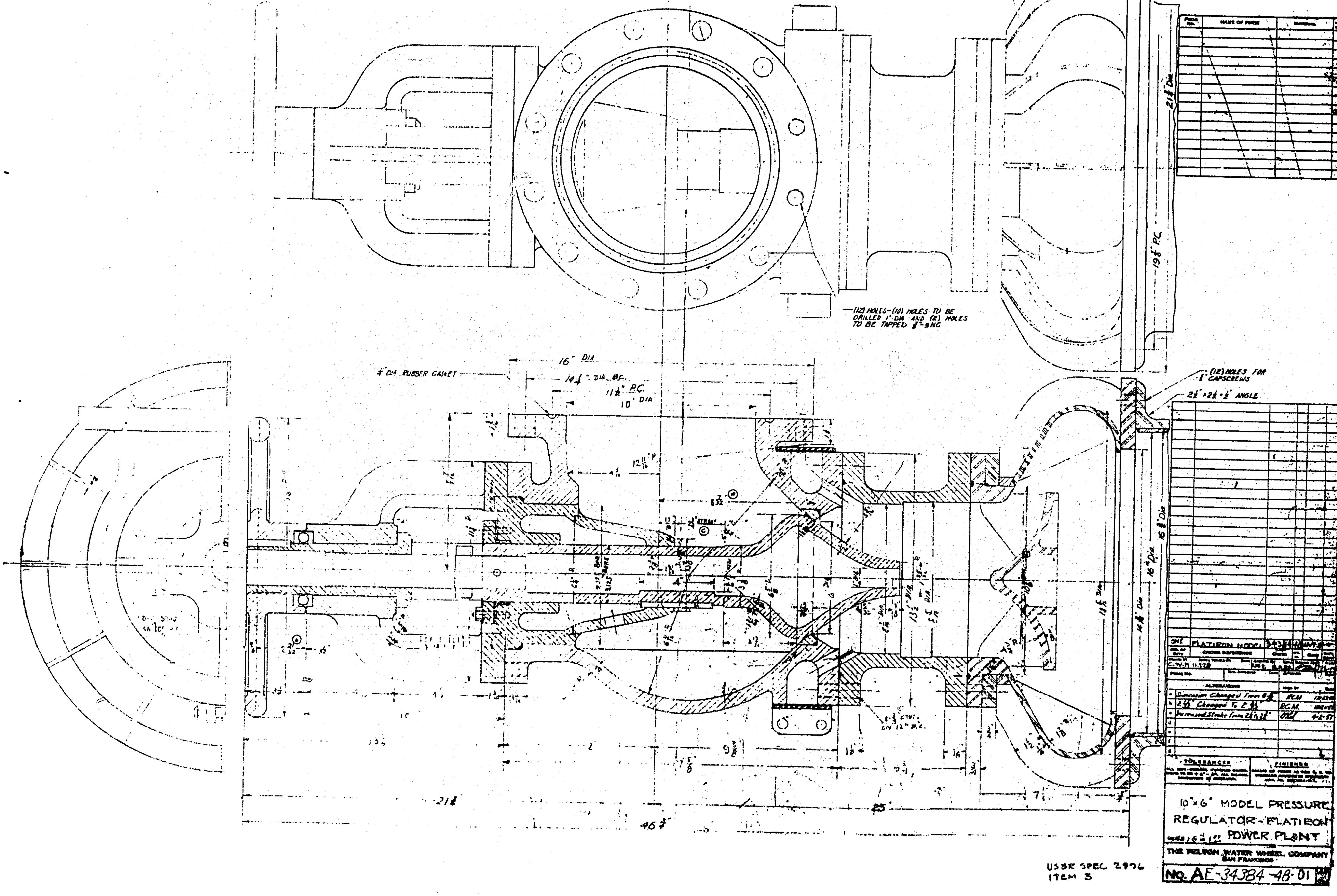
E—TOTAL HORSEPOWER VS TOTAL DISCHARGE

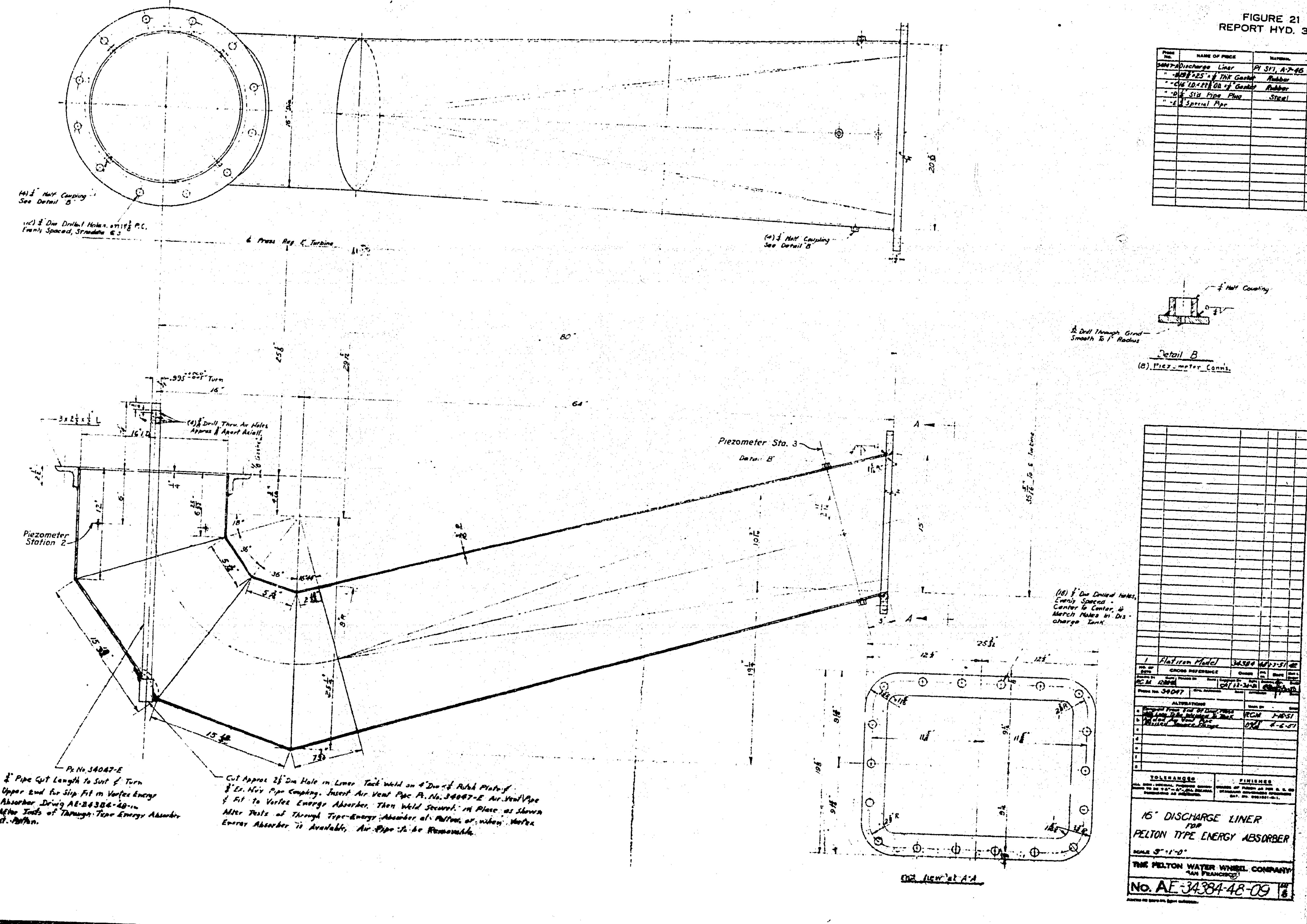
NOTE
These curves are replotted from the curves in the Pelton Water Wheel Company's report to the Bureau of Reclamation.

HIGH HEAD TESTS—FLATIRON MODEL TURBINE AND ENERGY ABSORBER

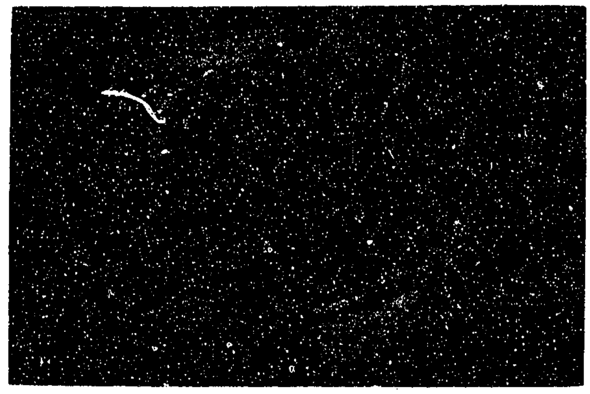
PERFORMANCE CURVES OF SF-4A RUNNER

DATA FROM 1:4.21 SCALE MODEL

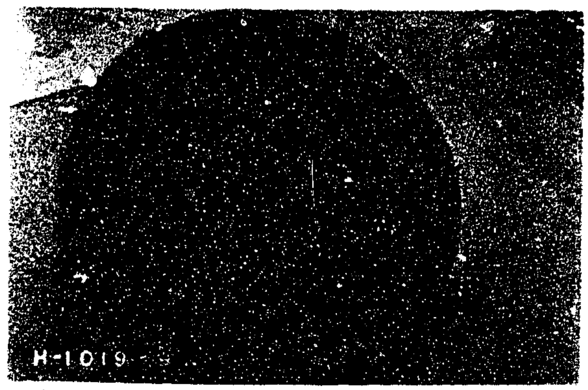

(12) HOLES-(10) HOLES TO BE DRILLED 1" DIA AND (2) HOLES TO BE TAPPED 7/8"-9NC
(12) HOLES FOR 7/8" CAPSCREWS
2½" x 2½" x ½" ANGLE
3/4" DIA RUBBER GASKET
16" DIA
14¼" DIA BF
11⅞" PC
10" DIA
21⅛"
46⅞"
19⅝" PC
21⅛" DIA
16⅛" DIA
14⅝" DIA
ALTERATIONS
Dimension Changed from
2 3/32 Changed To 2 3/8
Increased Stroke from
TOLERANCES
FINISHES
10" x 6" MODEL PRESSURE REGULATOR - FLATIRON POWER PLANT
THE PELTON WATER WHEEL COMPANY
SAN FRANCISCO
No. AE-34384-48-01
USBR SPEC 2926
ITEM 3


Detail B
(8) Piezometer Conn's.
¼" Half Coupling
Piezometer Sta. 3
Piezometer Station 2
Press Reg. ℄ Turbine
End View at A-A
16" DISCHARGE LINER
FOR
PELTON TYPE ENERGY ABSORBER
SCALE 3" = 1'-0"
THE PELTON WATER WHEEL COMPANY
SAN FRANCISCO
No. AE-34384-48-09

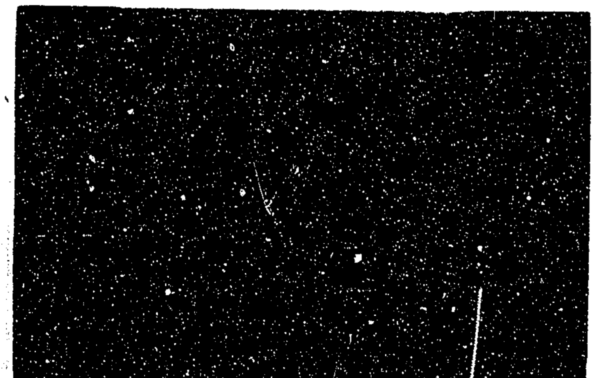
A. Pelton energy absorber installed for testing.



B. Flow spreader looking downstream.



C. Bowl and flow spreader looking upstream.

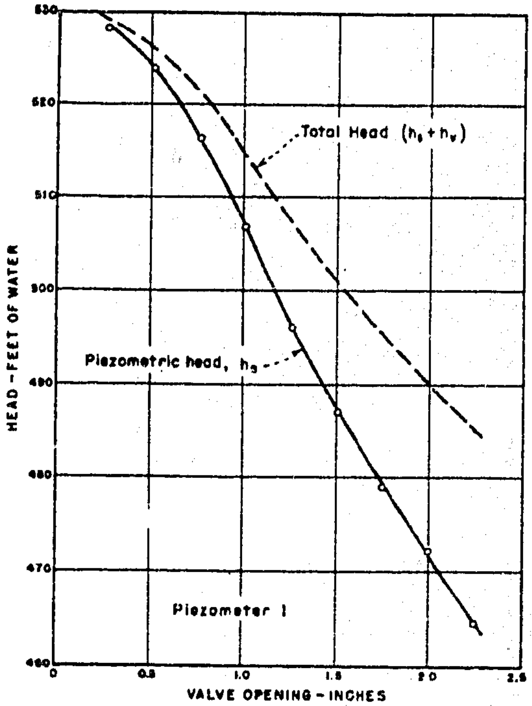


D. Bowl looking upstream.

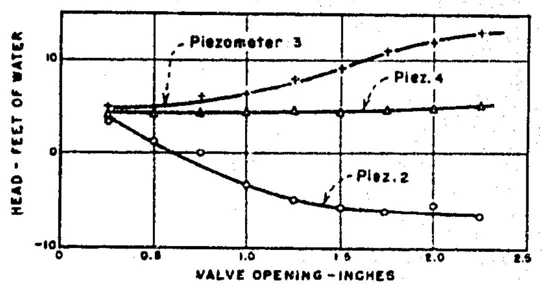
E. Discharge tube looking downstream.

HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER

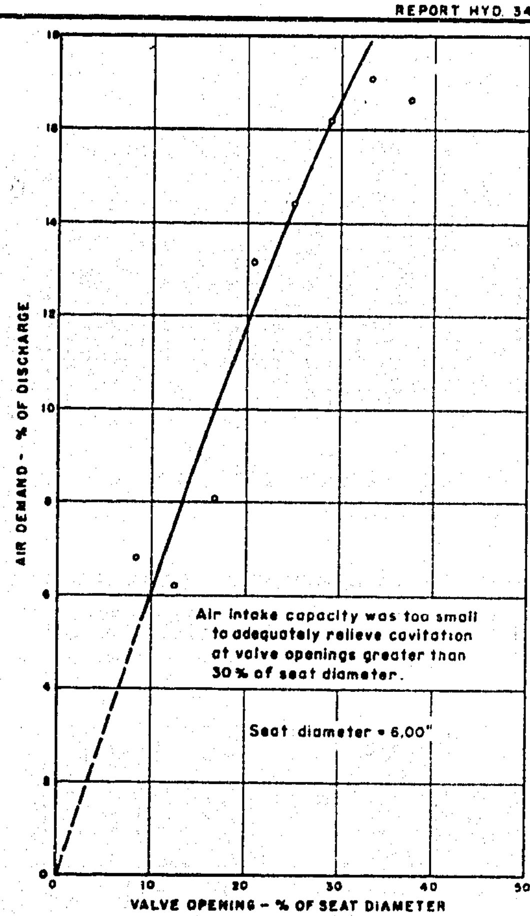
Pelton Energy Absorber (Pressure Regulator)
1:4.5 scale model



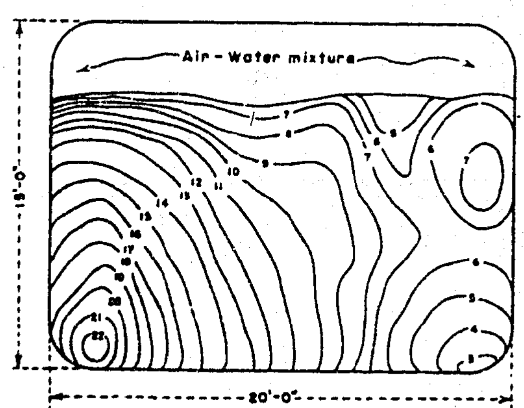
A-HEAD AT INLET TO BY-PASS VALVE



B - PRESSURES IN ENERGY ABSORBER

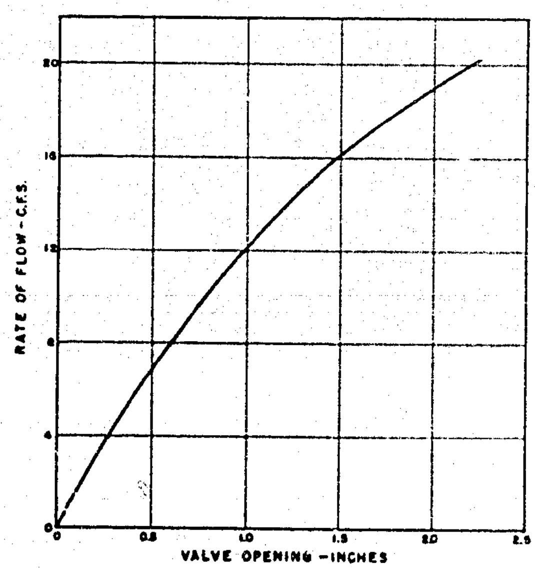


C - AMOUNT OF AIR REQUIRED TO QUIET CAVITATION



D-VELOCITY DISTRIBUTION AT OUTLET OF DRAFT TUBE. VIEW LOOKING DOWNSTREAM

(Q=16.60 cfs, valve opening $1\frac{1}{2}$ inches, air admitted.)



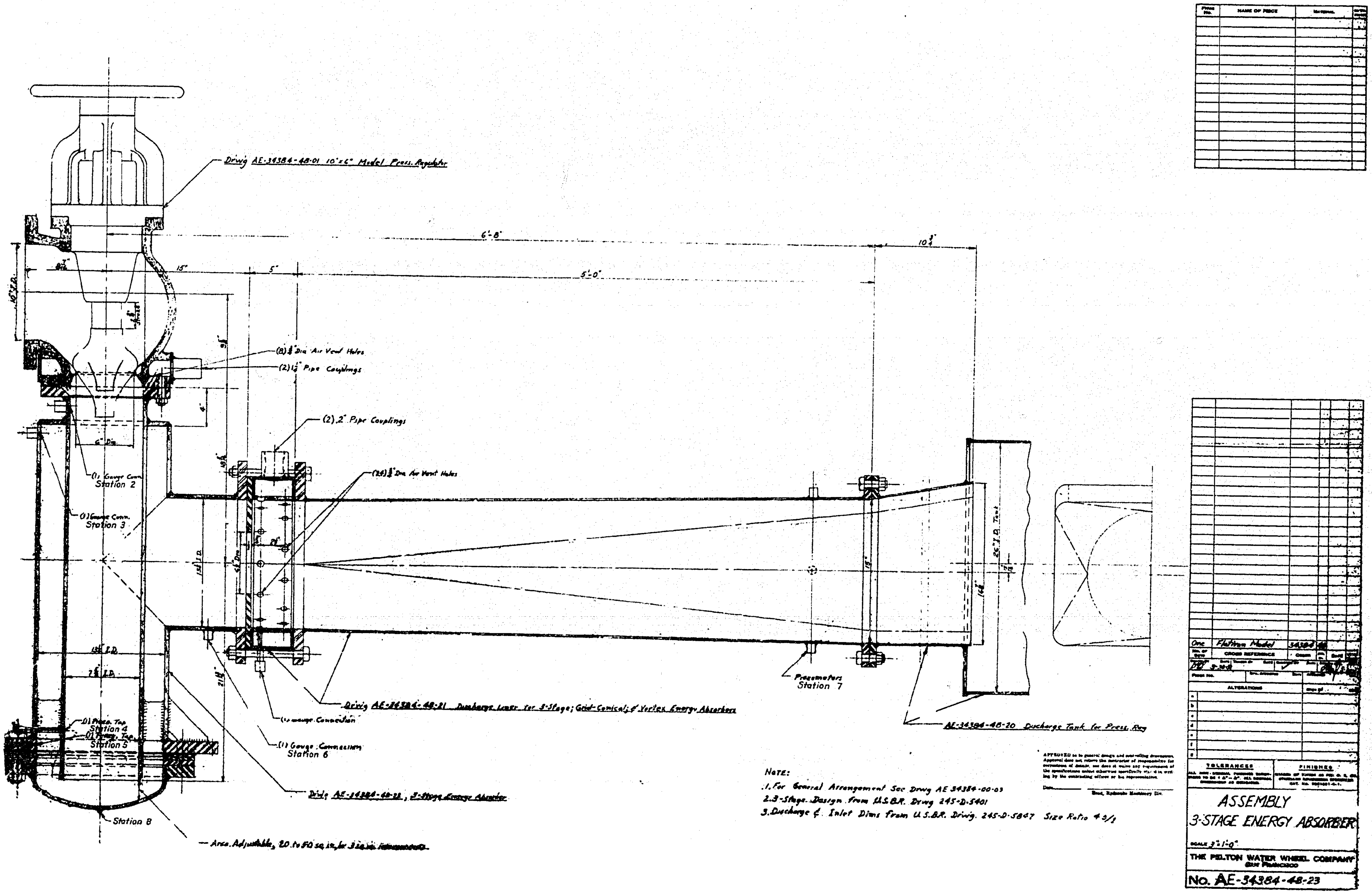
E-DISCHARGE THROUGH ABSORBER FOR 500 FOOT TOTAL HEAD

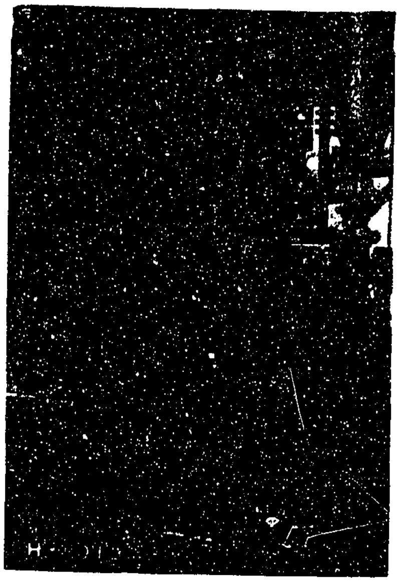
HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER

PERFORMANCE CURVES OF PELTON ENERGY ABSORBER

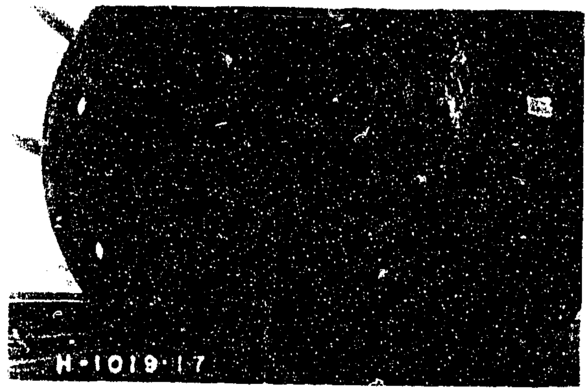
DATA FROM 1:4.5 SCALE MODEL

431

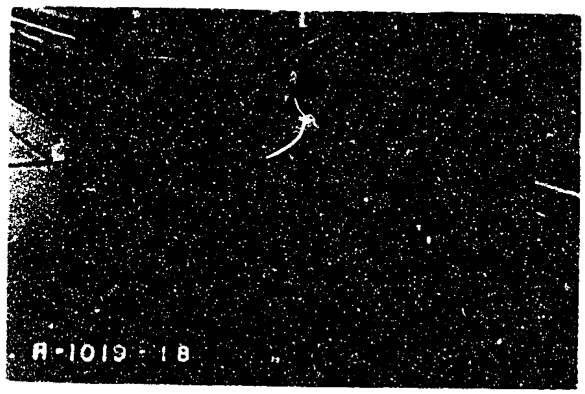

Drwg AE-34384-48-01 10"x6" Model Press. Regulator
6'-8"
10 3/4"
15"
5"
5'-0"
(8) 3/8" Dia Air Vent Holes
(2) 1 1/2" Pipe Couplings
(2) 2" Pipe Couplings
(24) 3/8" Dia Air Vent Holes
6" Dia.
(1) Gauge Conn. Station 2
(1) Gauge Conn. Station 3
13 1/2" I.D.
7 5/8" I.D.
(1) Piez. Tap Station 4
(1) Piez. Tap Station 5
Station 8
Piezometers Station 7
26" I.D. Tank
(1) Gauge Connection
(1) Gauge Connection Station 6
Drwg AE-34384-48-21 Discharge Liner for 3-Stage; Grid-Conical; & Vortex Energy Absorbers
Drwg AE-34384-48-22, 3-Stage Energy Absorber
AE-34384-48-20 Discharge Tank for Press. Reg
Area Adjustable, 20 to 50 sq. in. for 3 stage
Note:
1. For General Arrangement See Drwg AE 34384-00-03
2. 3-Stage Design from U.S.B.R. Drwg 245-D-5401
3. Discharge & Inlet Dims from U.S.B.R. Drwg. 245-D-5847 Size Ratio 4 3/1
NAME OF PIECE
MATERIAL
One Pelton Model 34384
CROSS REFERENCE
ALTERATIONS
TOLERANCES
FINISHES
ASSEMBLY
3-STAGE ENERGY ABSORBER
SCALE 3" = 1'-0"
THE PELTON WATER WHEEL COMPANY
SAN FRANCISCO
No. AE-34384-48-23



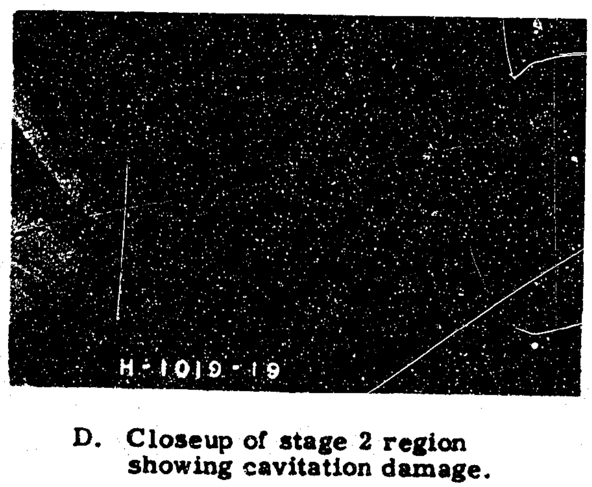
A. Three-stage energy absorber installed for testing.



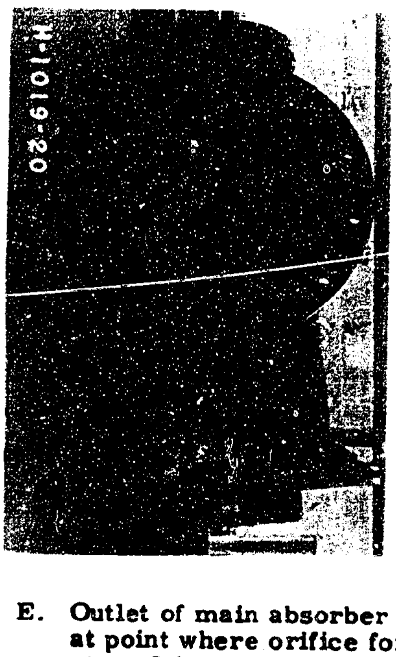
B. Inlet of absorber looking downstream.



C. Stage 2 of absorber with bottom cover removed.



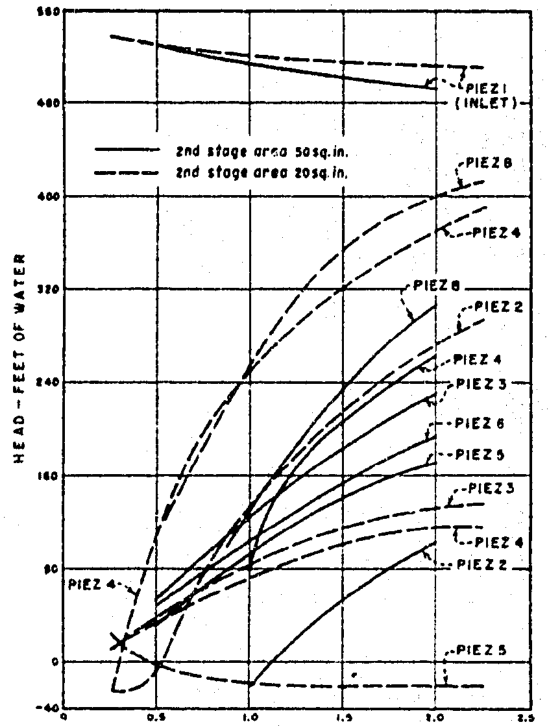
D. Closeup of stage 2 region showing cavitation damage.



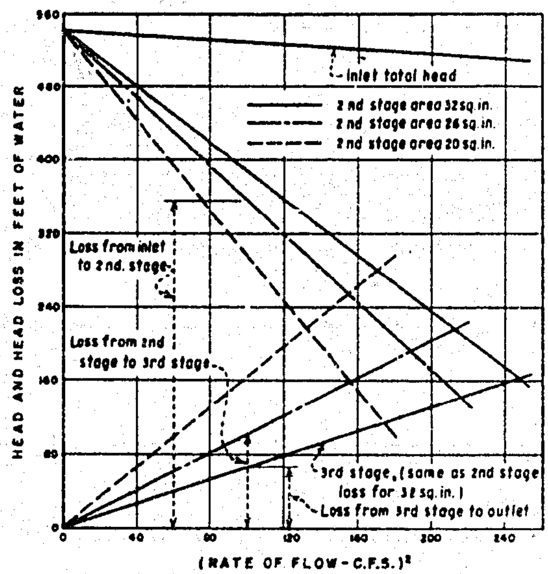
E. Outlet of main absorber at point where orifice for stage 3 is attached. Stage 2 is at bottom of photo.

HIGH HEAD TESTS - FLATIRON MODEL
TURBINE AND ENERGY ABSORBER

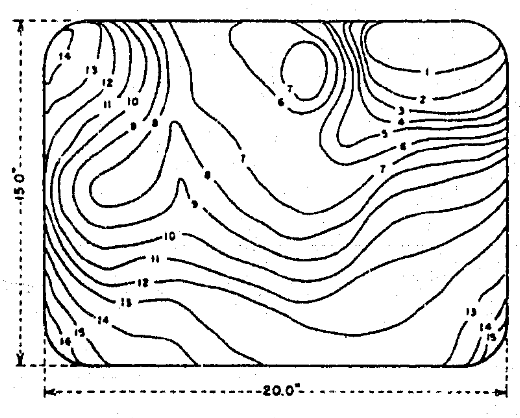
Three-stage Energy Absorber
1:4.5 scale model



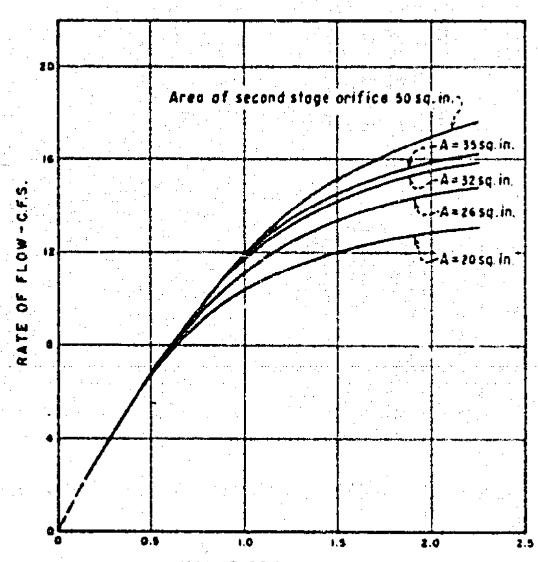
A-PRESSURES AT INLET AND WITHIN ENERGY ABSORBER



B-LOSSES IN ABSORBER WITH VARIOUS SECOND STAGE AREAS



C- VELOCITY DISTRIBUTION AT OUTLET OF DRAFT TUBE. VIEW LOOKING DOWNSTREAM
(Q=12.68 cfs, valve opening $1\frac{1}{4}$ inches. No air admitted at third stage.)



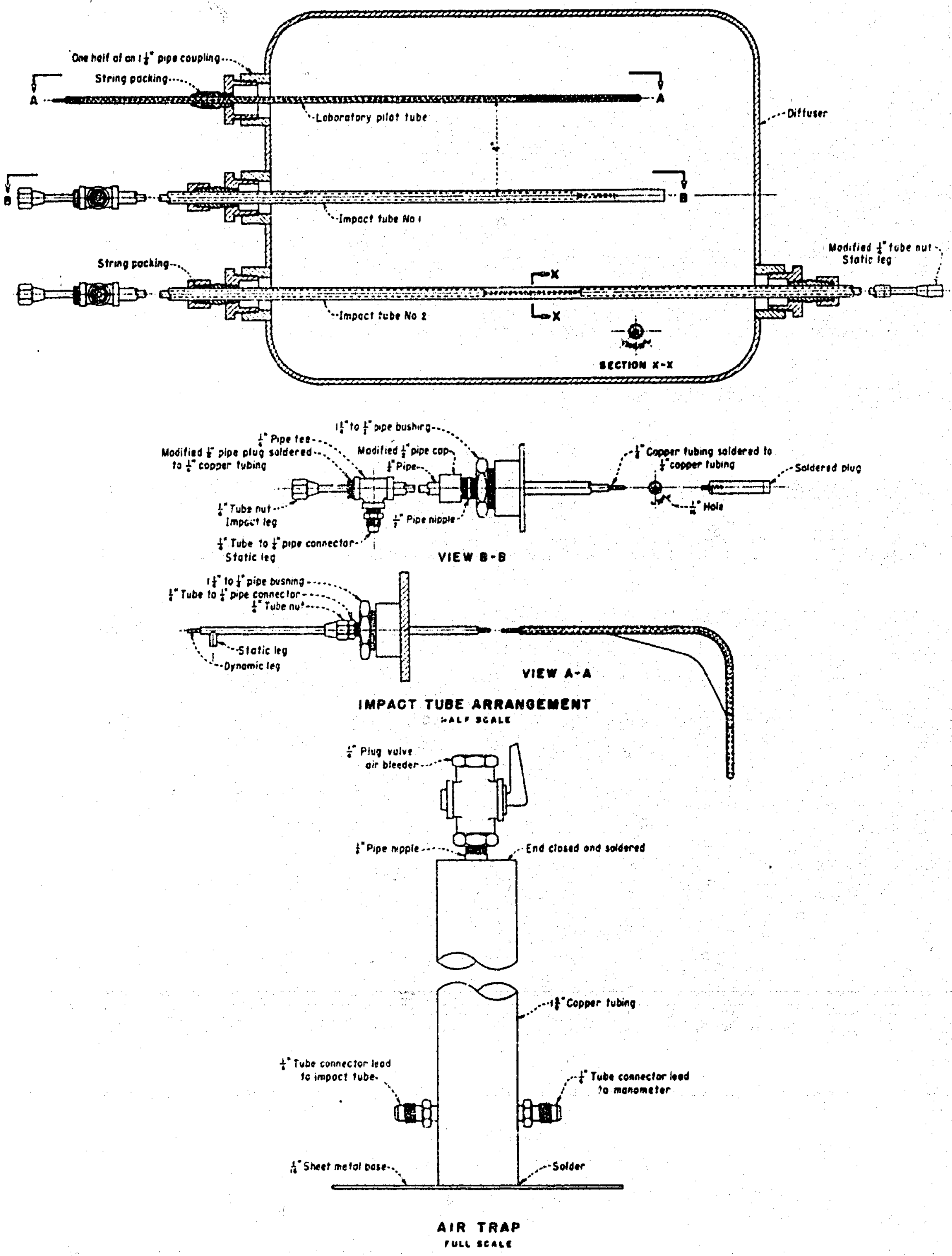
D-DISCHARGE THROUGH ABSORBER FOR 500 FOOT TOTAL HEAD

HIGH HEAD TESTS - FLATIRON MODEL TURBINE AND ENERGY ABSORBER

PERFORMANCE CURVES OF 3-STAGE ENERGY ABSORBER

DATA FROM 1:4.5 SCALE MODEL

431

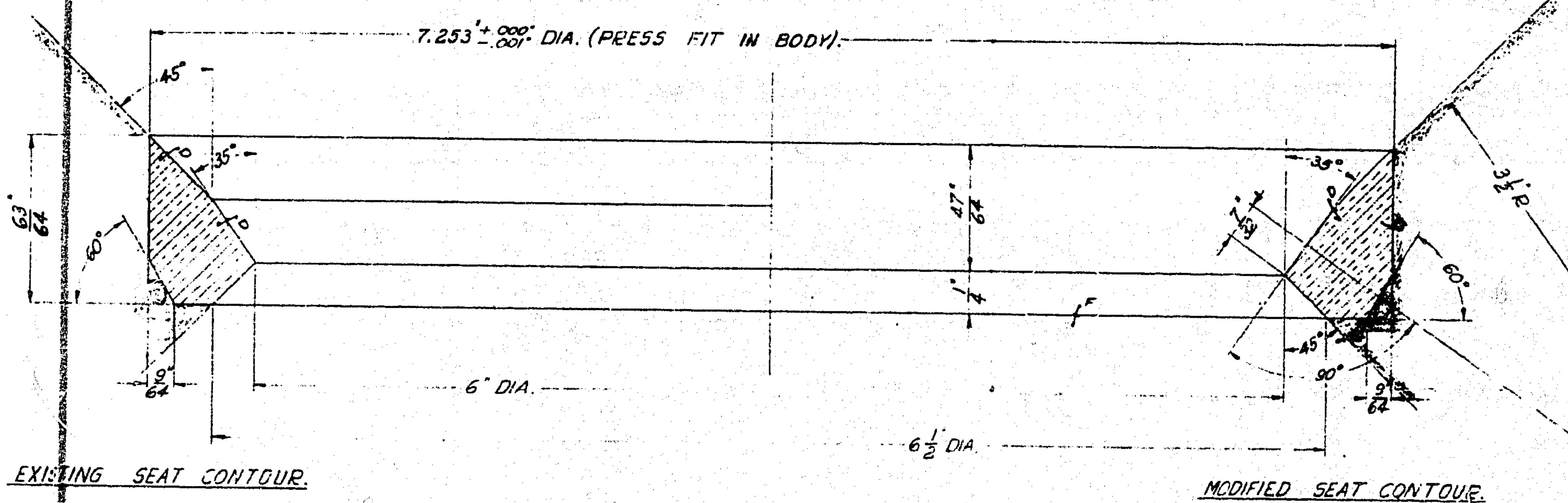


HIGH HEAD TESTS – FLATIRON MODEL TURBINE AND ENERGY ABSORBER

VELOCITY MEASURING EQUIPMENT AND STATIONS

1 : 4.5 SCALE MODEL

FIGURE 28
REPORT HYD. 348



TOLERANCES

FINISHES

MODIFIED
SEAT RING CONTOUR

SCALE 24" = 1'-0"

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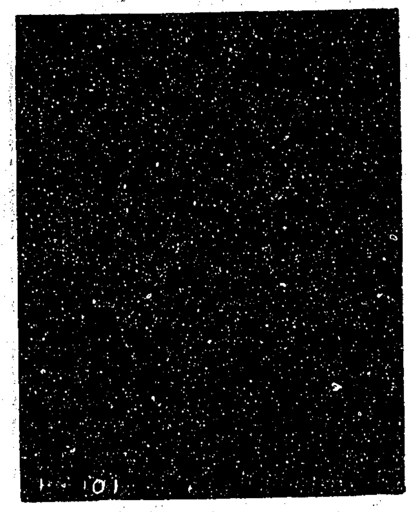
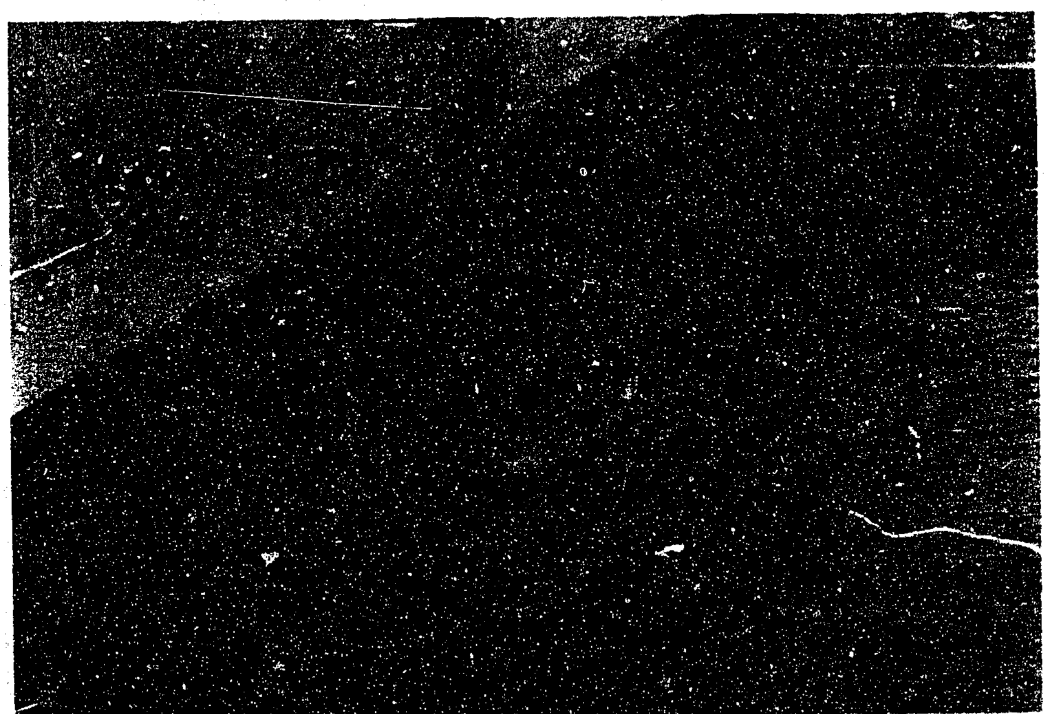
No. BE - 34384 - 48 - 50



A. Unhandy entrance to valve pit.



B. Repairing butterfly valve from rowboat.

HIGH HEAD TESTS - FLATIRON MODEL TURBINE
AND ENERGY ABSORBER

Valve Pit Entrance, and Butterfly Valve Repairs